APS March Meeting 2015
San Antonio, Texas
http://www.aps.org/meetings/march/index.cfm
How to keep your pants on: historic metamaterials and elasticity before the invention of elastic materials. How do you create stretching from an inextensible material? Remarkably, the centuries-old embroidery technique known as smocking accomplishes just this. With the recent explosion of origami-based engineering, the search is on for a set of design principles to generate materials with prescribed mechanical properties. This quickly becomes a complex mathematical question due to the strict constraints of rigid origami imposed by the inextensibility of paper. Softening these constraints by considering woven fabrics, which have two orthogonal inextensible directions and a skewed soft shear mode, opens up a zoo of possible configurations. We explore the emergence of elastic properties in smocked fabrics as functions of both fabric elasticity and smocking pattern.

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that have been used almost exclusively for macroscale structures are applied to dramatically enhance their stretchability. Specifically, we show using classical

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Using ideas from origami and differential geometry, I will discuss how deforming a non-Euclidean surface can be done either continuously or discontinuously, and

of Massachusetts, Amherst — Both natural and man-made structures benefit from having multiple mechanically stable states, from the quick snapping motion of hummingbird beaks to micro-textured surfaces with tunable roughness. Rather than discuss special fabrication techniques for creating bi-stability through material anisotropy, in this talk I will present several examples of how folding a structure can modify the energy landscape and thus lead to multiple stable states. Using ideas from origami and differential geometry, I will discuss how deforming a non-Euclidean surface can be done either continuously or discontinuously, and explore the effects that global constraints have on the ultimate stability of the surface.

We demonstrate can have up to six stable states. We extend our results to non-Euclidean vertices, which enables us fine-control over the number of minima. Our results lay the foundation for building designer, origami-based shape-shifting structures.

Multi-stability in folded shells: non-Euclidean origami, ARTHUR EVANS, University of Massachusetts, Amherst — Both natural and man-made structures benefit from having multiple mechanically stable states, from the quick snapping motion of hummingbird beaks to micro-textured surfaces with tunable roughness. Rather than discuss special fabrication techniques for creating bi-stability through material anisotropy, in this talk I will present several examples of how folding a structure can modify the energy landscape and thus lead to multiple stable states. Using ideas from origami and differential geometry, I will discuss how deforming a non-Euclidean surface can be done either continuously or discontinuously, and explore the effects that global constraints have on the ultimate stability of the surface.

9:12AM A44.00005 Prediction of the force required to unwrap a thin-film origami structure\textsuperscript{1}, LEE WILSON, SERGIO PELLEGRINO, Caltech — We consider thin film membranes wrapped around a polygonal hub according to the origami crease pattern developed by Guest and Pellegrino [1]. The problem of unwrapping such membranes is important for applications such as space solar sails. Their deployment can be controlled by displacing four edge points radially outwards. During deployment the film buckles multiple times, creating a complex deployment force profile. We have used finite element simulations to investigate how different models of the creases affect the predicted force profile and we have compared the results of our simulations with experimental results for Kapton thin film thicknesses of 50um, 25um, 12.5um and 7.5um. The deployment force profile is also highly dependent on the initial packaged configuration of the film, which in our model is obtained by simulating the folding process from a flat state. [1] S.D Guest and S. Pellegrino, Proc. First Int. Seminar on Struct. Morphology, R. Motro and T. Wester, eds. (1992) pp 203-215

\textsuperscript{1}This work was supported by NSF Grant No. 1353006

9:24AM A44.00006 Making the Cut: Lattice Kirigami Rules\textsuperscript{1}, TOEN CASTLE, YIGIL CHO, XIONGTING GONG, EUYEON JUNG, DANIEL SUSSMAN, SHU YANG, RANDALL KAMiEN, University of Pennsylvania — Complex 3D structures can be built by bending and folding a flat sheet, as is done in origami. This paradigm can be extended by cutting and gluing the sheet as well as folding. The principles manifest in manipulating a piece of paper can translate across many length scales, limited only by fabrication methods. We explore and develop a simple set of rules that apply to cutting, pasting, and folding honeycomb lattices. We consider origami-like structures that are extrinsically flat away from zero-dimensional sources of Gaussian curvature and one-dimensional sources of mean curvature, and our cutting and pasting rules maintain the intrinsic bond lengths on both the lattice and its dual lattice. We find that a small set of rules is allowed, providing a framework for exploring and building kirigami - folding, cutting, and pasting the edges of paper.

\textsuperscript{1}Support from NSF DMR12-62047.

9:36AM A44.00007 Kirigami for Two-Dimensional Electronic Membranes\textsuperscript{1}, ZENAN QI\textsuperscript{2}, Boston University, DARIO BAHAMON\textsuperscript{3}, Mackenzie Presbyterian University, DAVID CAMPBELL\textsuperscript{4}, HAROLD PARK\textsuperscript{5}, Boston University — Two-dimensional materials have recently drawn tremendous attention because of their unique properties. In this work, we introduce the notion of two-dimensional kirigami, where concepts that have been used almost exclusively for macroscale structures are applied to dramatically enhance their stretchability. Specifically, we show using classical molecular dynamics simulations that the yield and fracture strains of graphene and MoS\textsubscript{2} can be enhanced by about a factor of three using kirigami as compared to standard monolayers. Finally, using graphene as an example, we demonstrate that the kirigami structure may open up interesting opportunities in coupling to the electronic behavior of 2D materials.

\textsuperscript{1}Authors acknowledge Mechanical Engineering and Physics departments at Boston University, and Mackgrafe at Mackenzie Presbyterian University.

\textsuperscript{2}Department of Mechanical Engineering

\textsuperscript{3}Graphene and Nano-Materials Research Center

\textsuperscript{4}Department of Physics

\textsuperscript{5}Department of Mechanical Engineering
and Mechanisms II
214D - 
small and large scales.
we have shown that the folded materials possess properties as remarkable as those of Miura-ori on which there is a lot of recent research. We have also introduced
innovative design of mechanical metamaterials for which the material properties arise from their geometry and structural layout. Most research on origami-
Urbana-Champaign, GLAUCIO PAULINO, University of Illinois at Urbana Champaign — Origami has shown to be a substantial source of inspiration for


10:00AM A44.00009 Optimization of Actuating Origami Networks1, PHILLIP BUSKOH, Air Force Research Laboratory, KAZUKO FUCHI, Wright State Research Institute, GIORGIO BAZZAN, JAMES JOO, REICH GREGORY, RICHARD VAIA, Air Force Research Laboratory — Origami structures morph between 2D and 3D conformations along predetermined fold lines that efficiently program the form, function and
mobility of the structure. By leveraging design concepts from action origami, a subset of origami art focused on kinematic mechanisms, reversible folding patterns for applications such as solar array packaging, tunable antennas, and deployable sensing platforms may be designed. However, the enormity of the design space and the need to identify the requisite actuation forces within the structure places a severe limitation on design strategies based on intuition and geometry alone. The present work proposes a topology optimization method, using truss and frame element analysis, to distribute foldline mechanical properties within a reference crease pattern. Known actuating patterns are placed within a reference grid and the optimizer adjusts the fold stiffness of the network to optimally connect them. Design objectives may include a target motion, stress level, or mechanical energy distribution. Results include the validation of known action origami structures and their optimal connectivity within a larger network. This design suite offers an important step toward systematic incorporation of origami design concepts into new, novel and reconfigurable engineering devices.

3This research is supported under the Air Force Office of Scientific Research (AFOSR) funding, LRIR 13RQ02COR.

10:12AM A44.00010 Origami folding of polymer sheets by inkjet printing, YING LIU, BRANDI SHAW, MICHAEL D. DICKEY, JAN GENZER, North Carolina State University — In analogy to the ancient Japanese art of paper folding (Origami), self-folding is an attractive strategy to induce the formation of three-dimensional (3D) objects with well-defined shapes and dimensions using conventional two-dimensional (2D) patterning techniques, such as lithography and inkjet printing. Self-folding can be applied in the areas of reconfigurable devices, actuators, and sensors. Here we demonstrate a simple method for self-folding of polymer sheets utilizing localized light absorption on selected areas of the pre-strained polymer sheet. The ink is patterned via a desktop printer and it defines the location of the ‘hinge’ on the sheet. The inked areas on the 2D sheet absorb light preferentially, thus causing the polymer sheet to fold locally in the inked areas. The temperature gradients through the depth of the sheet induce localized shrinkage and the sheet folds within seconds. This patterned polymer sheets act as shape memory materials which can be programmed to fold into various 3D structures based on the nature of the light source, the shape and size of the ink patterns, and ink property. By controlling the aforementioned parameters we achieve a complete control of the time and degree of folding, which ultimately govern the final 3D shape of the folded object.

10:24AM A44.00011 Actuated 3D origami-like structures with tunable volume and stiffness, JOHANNES OVERVELDE, TWAN DE JONG, JAMES WEAVER, CHUCK HOBERMAN, KATIA BERTOLDI, Harvard University — Recent years have seen an uprise of new materials with interesting and unusual properties that result from their regular periodic microstructure. Origami-based metamaterials based on the Miura fold pattern have recently gained a lot of attention for their ability to drastically change their shape and therewith creating a programmable metamaterial. In this work, we present a completely new class of actuated 3D foldable materials with three degrees of freedom that can drastically change their shape and volume by folding. These materials do not only change their shape, but also have a tunable stiffness that can vary two orders of magnitude by making use of contact interaction between different parts of the material. We experimentally show their effectiveness by building a metamaterial consisting of 64 unit cells and by incorporating local inflatable actuators in the material to enable large on demand changes in shape and stiffness.

10:36AM A44.00012 Stress Focusing in Creased Shells, SARAH SELDEN, ARTHUR EVANS, NAKUL BENDE, RYAN HAYWARD, CHRISTIAN SANTANGELO, Univ of Mass - Amherst — Upon indentation, thin shells react by localizing strain energy in polygonal structures as opposed to a uniform axisymmetric distribution. While the formation of these localized structures is well-characterized for perfect shells, the introduction of a crease fundamentally changes the nature of the shell's deformation. We perform finite element simulations, in tandem with experiments to explore the effect of a creased shell on the energy landscape. We find that the crease induces a new symmetry-breaking localization that does not appear in perfect shells, and we explore the deformation characteristics of the creased shell over a wide range of crease sizes, shell thickness, and crease orientations.

10:48AM A44.00013 Folding and bending of self-assembled nanoparticle membranes, YIFAN WANG, The University of Chicago, JIANHUI LIAO, Peking University, SEAN MCBRIDE, EFI EFRATI, The University of Chicago, XIAO-MIN LIN, Argonne National Laboratory, HEINRICH JAEGGER, The University of Chicago — We demonstrate that self-assembled nanoparticle monolayers can be folded into 3 dimensional holohedral structures. Using an Atomic Force Microscope (AFM), indentation measurements were made on these nanoparticle scrolls, and the bending modulus of the nanoparticle membrane is obtained for the first time. The resulting bending modulus is two orders of magnitude larger than that predicted by classical continuum elastic theory, we show this can be explained by a micropolar theory as the material properties arise from their geometry and structural layout. Most research on origami-inspired materials relies on known patterns, especially on classic Miura-ori pattern. In the present research, we have created origami-inspired metamaterials and we have shown that the folded materials possess properties as remarkable as those of Miura-ori on which there is a lot of recent research. We have also introduced and placed emphasis on several important concepts that are confused or overlooked in the literature, e.g. concept of planar Poisson’s ratio for folded materials from different conceptual viewpoints, and we have clarified the importance of such concepts by applying them to the folded sheet metamaterials introduced in our research. The new patterns are appropriate for a broad range of applications, from mechanical metamaterials to deployable and kinetic structures, at both small and large scales.

Monday, March 2, 2015 11:15AM - 2:15PM — Session B44 GSNF GSOFT DPOLY: Focus Session: Extreme Mechanics: Origami, Kirigami and Mechanisms II 214D -

11:15AM B44.00001 Unravelling Origami Metamaterial Behavior, MARYAM EIDINI, University of Illinois at Urbana-Champaign, GLAUCIO PAULINO, University of Illinois at Urbana-Champaign — Origami has shown to be a substantial source of inspiration for innovative design of mechanical metamaterials for which the material properties arise from their geometry and structural layout. Most research on origami-inspired materials relies on known patterns, especially on classic Miura-ori pattern. In the present research, we have created origami-inspired metamaterials and we have shown that the folded materials possess properties as remarkable as those of Miura-ori on which there is a lot of recent research. We have also introduced and placed emphasis on several important concepts that are confused or overlooked in the literature, e.g. concept of planar Poisson’s ratio for folded materials from different conceptual viewpoints, and we have clarified the importance of such concepts by applying them to the folded sheet metamaterials introduced in our research. The new patterns are appropriate for a broad range of applications, from mechanical metamaterials to deployable and kinetic structures, at both small and large scales.
Both 1D systems of periodic folds and 2D Miura-Ori patterns are investigated. The dispersion relations are calculated by finite element simulations on the underlying lattice. Simple prototypes built out of triangular plates joined by hinges provide a visual demonstration of these modes.

The existence of the modes is determined by the interplay between two Berry phases – the Burgers vector of the dislocation and a topological “polarization” to the electronic edge states of topological insulators. We show that dislocations in such metamaterials are associated with soft modes of topological origin.

The properties of a recently introduced class of topological metamaterials. These are special periodic frameworks which exhibit localized edge modes, analogous constituent elements of the structure. We demonstrate a novel way to introduce approximate mechanisms at desired locations in a metamaterial, by exploiting connected by springs or rigid bars – underlies the structural integrity of bridges, the response of granular materials, and the design of metamaterials with unusual mechanical properties. A fundamental question governing rigidity is the existence of mechanisms: motions that do not significantly stretch or compress the constituent elements of the structure. We demonstrate a novel way to introduce approximate mechanisms at desired locations in a metamaterial, by exploiting the properties of a recently introduced class of topological metamaterials. These are special periodic frameworks which exhibit localized edge modes, analogous to the electronic edge states of topological insulators. We show that dislocations in such metamaterials are associated with soft modes of topological origin.

The existence of the modes is determined by the interplay between two Berry phases – the Burgers vector of the dislocation and a topological “polarization” characterizing the underlying lattice. Simple prototypes built out of triangular plates joined by hinges provide a visual demonstration of these modes.

Supported by FOM and D-TIP.
1:27PM B44.00010 Quantitative emergence of autocatalytic information-coding polymers 1
ALEXEI TKACHENKO, SERGEI MASLOV, Brookhaven National Laboratory — Self-replicating systems based on information-coding polymers are of crucial importance in biology. They also recently emerged as a paradigm in design on nano- and micro-scales. We present a general theoretical and numerical analysis of the problem of spontaneous emergence of autocatalysis for heteropolymers capable of template-assisted ligation driven by cyclic changes in the environment. Our central result is the existence of the first order transition between the regime dominated by free monomers and that with a self-sustaining population of sufficiently long oligomers. We provide a simple mathematically tractable model that predicts the parameters for the onset of autocatalysis and the distribution of behaviors. 

1:39PM B44.00011 Associative memory through rigid origami 1
ARVIND MURUGAN, MICHAEL BRENNER, Harvard University — Mechanisms such as Miura Ori have proven useful in diverse contexts since they have only one degree of freedom that is easily controlled. We combine the theory of rigid origami and associative memory in frustrated neural networks to create structures that can “learn” multiple generic folding mechanisms and yet can be robustly controlled. We show that such rigid origami structures can "recall" a specific learned mechanism when induced by a physical impulse that only need resemble the desired mechanism (i.e. robust recall through association). Such associative memory in matter, seen before in self-assembly, arises due to a balance between local promiscuity (i.e., many local degrees of freedom) and global frustration which minimizes interference between different learned behaviors. Origami with associative memory can lead to a new class of deployable structures and kinetic architectures with multiple context-dependent behaviors.

1:51PM B44.00012 Hiding the weakness: structural robustness using origami design 1
BING LIU, Physics Department, Cornell University, CHRISTIAN SANTANGELO, Department of Physics, University of Massachusetts, Amherst, ITAI COHEN, Physics Department, Cornell University — A non-deformable structure is typically associated with infinitely stiff materials that resist distortion. In this work, we designed a structure with a region that will not deform even though it is made of arbitrarily compliant materials. More specifically, we show that a foldable sheet with a circular hole in the middle can be deformed externally with the internal geometry of the hole unaffected. Instead of strengthening the local stiffness, we fine tune the crease patterns so that all the soft modes that can potentially deform the internal geometry are not accessible through strain on the external boundary. The inner structure is thus protected by the topological mechanics, based on the detailed geometry of how the vertices in the foldable sheet are connected. In this way, we isolate the structural robustness from the mechanical properties of the materials, which introduces an extra degree of freedom for structural design.

2:03PM B44.00013 Untangling the mechanics versus topology of overhand knots 1
PEDRO REIS, MOHAMMAD JAWED, Massachusetts Institute of Technology, PETER DIELEMAN, Leiden University, BASILE AUDOLY, Sorbonne Universités, UPMC Univ Paris & CNRS — We study the interplay between mechanics and topology of overhand knots in slender elastic rods. We perform precision desktop experiments of overhand knots with increasing values for the crossing number (our measure of topology) and characterize their mechanical response through tension-displacement tests. The tensile force required to tighten the knot is governed by an intricate balance between topology, bending, friction, and contact forces. Digital imaging is employed to characterize the configuration of the contact braid as a function of crossing number. A robust scaling law is found for the pulling force in terms of the geometric and topological parameters of the knot. A reduced theory is developed, which predictively rationalizes the process.

Monday, March 2, 2015 11:15AM - 2:03PM –
Session B50 GSNP: Statistical Mechanics: Optimization and Algorithms
11:15AM B50.00001 Spontaneous emergence of autocatalytic information-coding polymers 1
ALEXEI TKACHENKO, SERGEI MASLOV, Brookhaven National Laboratory — Self-replicating systems based on information-coding polymers are of crucial importance in biology. They also recently emerged as a paradigm in design on nano- and micro-scales. We present a general theoretical and numerical analysis of the problem of spontaneous emergence of autocatalysis for heteropolymers capable of template-assisted ligation driven by cyclic changes in the environment. Our central result is the existence of the first order transition between the regime dominated by free monomers and that with a self-sustaining population of sufficiently long oligomers. We provide a simple mathematically tractable model that predicts the parameters for the onset of autocatalysis and the distribution of chain lengths, in terms of monomer concentration, and two fundamental rate constants. Another key result is the emergence of the kinetically-limited optimal overlap length between a template and its two substrates. Template-assisted ligation allows for heritable transmission of information encoded in oligomer sequences thus opening up the possibility of long-term memory and evolvability of such systems.
Research was carried out in part at the Center for Functional Nanomaterials at Brookhaven National Laboratory, which is supported by the U.S. Department of Energy, Office of Basic Energy Sciences, under Contract No. DE-AC02-98CH10886. Work at Biosciences Department was supported by US Department of Energy Office of Biological Research Grant PM-031.

11:27AM B50.00002 Evidence against a field mediated description of short-range spin glasses revealed through thermal boundary conditions 1
JONATHAN MACHTA, WENLONG WANG, University of Massachusetts Amherst, HELMUT KATZGRABER, Texas A&M University — A theoretical description of the low-temperature phase of short-range spin glasses has remained elusive for decades. It is not known if there is a single pair of pure states as predicted by the droplet model, or infinitely many pure states, as predicted by mean field theory. Here we study the three-dimensional Edwards-Anderson Ising spin glass in thermal boundary conditions using population annealing Monte Carlo. In thermal boundary conditions all eight combinations of periodic vs antiperiodic boundary conditions in the three spatial directions appear in the ensemble with their respective Boltzmann weights, thus minimizing finite-size corrections due to domain walls. From the relative weighting of the eight boundary conditions for each disorder instance a single stiffness is defined, and its typical value is shown to grow with system size according to a stiffness exponent. An extrapolation to the large-system-size limit is consistent with a single pair of pure states in every volume but incompatible with the mean field, replica symmetry breaking picture.

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1Supported in part by NSF DMR-1151387 and DMR-1208046
11:39 AM B50.00003 Probing temperature chaos through thermal boundary conditions\textsuperscript{1}, WEN-LONG WANG, JONATHAN MACHTA, University of Massachusetts Amherst, HELMUT KATZGRABER, Texas A&M University — Using population annealing Monte Carlo, we numerically study temperature chaos in the three-dimensional Edwards-Anderson Ising spin glass using thermal boundary conditions. In thermal boundary conditions all eight combinations of periodic vs antiperiodic boundary conditions in the three spatial directions appear in the ensemble with their respective Boltzmann weights, thus minimizing finite-size corrections due to domain walls. By studying salient features in the specific heat we show evidence of temperature chaos. Of a chaotic phase that the step bumps are mainly caused by system-size excitations where the free energy of two boundary conditions cross. Furthermore, we study the scaling of both entropy and energy at boundary condition crossings and find that the scaling of the energy is very different from the scaling obtained by a simple change of boundary conditions. We attribute this difference to the stronger finite-size effects induced via a simple change of boundary conditions. Finally, we show that temperature chaos occurs more frequently at higher temperatures within the spin-glass phase and for larger system sizes, while the normalized distribution function with respect to temperature is about the same for different system sizes.

\textsuperscript{1}The work is supported from NSF (Grant No. DMR-1208046).

11:51 AM B50.00004 Effective Hamiltonians of 2D Spin Glass Clusters, COLIN CLEMENT, Cornell University, DANilo LIARTE, University of Sao Paulo, ALAN MIDDLETON, Syracuse University, JAMES SETHNA, Cornell University — We have a method for directly identifying the clusters which are thought to dominate the dynamics of spin glasses. We also have a method for generating an effective Hamiltonian treating each cluster as an individual spin. We used these methods on a 2D Ising spin glass with Gaussian bonds. We study these systems by generating samples and correlation functions using a combination of Monte Carlo and high-performance numerically exact Pfaffian methods. With effective cluster Hamiltonians we can calculate an ensemble average of the original clusters and perform a scaling analysis. The scaling exponents found are consistent with Domain-Vail Renormalization Group methods, and probe all length scales. We can also study the flow of these effective Hamiltonians by clustering the clustered spins, and we find that our hard spin Hamiltonians at high temperature retain accurate low-temperature fluctuations when compared to their parent models.

12:03PM B50.00005 Overfrustrated and Underfrustrated Spin-Glasses in d=3 and d=2: Evolution of Phase Diagrams and Chaos Including Spin-Glass Order in d=2, EFE ILKER, Sabanci University, A. NIHAT BERKER, Sabanci University, and MIT — In spin-glass (SG) systems, frustration can be adjusted continuously and considerably, without changing the antiferromagnetic (AF) bond probability $p$, by using locally correlated quenched randomness, both on hypercubic and hierarchical lattices [1]. With removal of $51\%$ frustration, a SG phase occurs in $d=2$. With addition of $33\%$ frustration, the SG phase disappears in $d=3$. In general, frustration lowers the SG ordering temperature. At low temperatures, increased frustration favors the spin-glass phase (before it disappears) over ferromagnetic (F) and AF phases. When any amount of frustration is introduced, chaotic rescaling of local interactions occurs in the SG phase. Chaos increases with increasing frustration. The distinct Lyapunov exponents of different phases and phase boundaries are calculated. From entropy and specific-heat curves in $d=3$, it is seen that frustration lowers in temperature the onsets of long- and short-range orders in spin-glass phases, more effectively on the former. From entropy versus $p$, it is seen that ground-state and low-temperature entropy already mostly sets in within the F and AF phases, before the SG phase is reached.


12:15PM B50.00006 The cavity method for phase transitions in sparse reconstruction algorithms, MOHAMMAD RAMEZANALI, Rutgers University, PARTHITA MITRA, Cold Spring Harbor Laboratory, ANIRVAN SENGUPTA, Rutgers University — Compressed sensing methods are capable of reconstructing high-dimensional sparse signals using a limited amount of measurements under certain conditions. The boundaries of good performance of compressed sensing methods are associated with certain phase transitions when the number of variables go to infinity. Many compressed sensing methods are formulated as optimization problems. Usual statistical physics approach to this problem involves inventing a finite temperature statistical system whose problems are equivalent to the compressed sensing problem. Although the replica trick has been very successful in reproducing the observations, the replica trick and the zero-temperature limit obscure the essential reasons for failure of a compressed sensing algorithm. In this work, we employ the cavity method to give an alternative derivation of the phase transitions, working solely with the zero-temperature limit and providing insight into the origin of different terms in the mean field self-consistency equations. The cavity method naturally invokes a susceptibility which is central to understanding different phases in this system, and could be generalized to a much broader class of compressed sensing problems.

12:27PM B50.00007 Multiply charged monopoles in cubic dimer model, SREEJITH GANESH JAYA, Max Planck Institute for Physics of Complex Systems, STEPHEN POWELL, The University of Nottingham — The classical cubic dimer model is a 3D statistical mechanical system whose degrees of freedom are dimers that occupy the edges between nearest neighbour vertices of a cubic lattice. Dimer occupations are subject to the local constraint that every vertex is associated with exactly one dimer. In the presence of an aligning interaction, it is known that the system exhibits long-range order at zero-temperature and providing insight into the origin of different terms in the mean field self-consistency equations. The cavity method naturally invokes a temperature version of the problem, analyzing the mean field theory via replica trick, and, then taking the zero temperature limit. Although this method has been successful in reproducing the observations, the replica trick and the zero-temperature limit obscure the essential reasons for failure of a compressed sensing algorithm. In this work, we employ the cavity method to give an alternative derivation of the phase transitions, working solely with the zero-temperature limit and providing insight into the origin of different terms in the mean field self-consistency equations. The cavity method naturally invokes a susceptibility which is central to understanding different phases in this system, and could be generalized to a much broader class of compressed sensing problems.

12:39PM B50.00008 A matrix product state method for solving combinatorial optimization problems\textsuperscript{1}, S.S. PELTON, University of Central Florida, C. CHAMON, Boston University, E.R. MUCCIOLLO, University of Central Florida — We present a method based on a matrix product state representation to solve combinatorial optimization problems. All constraints are met by mapping Boolean gates into projection operators and applying operators sequentially. The method provides exact solutions with high success probability, even in the case of frustrated systems. The computational cost of the method is controlled by the maximum relative entropy of the system. Results of numerical simulations for several types of problems will be shown and discussed.

\textsuperscript{1}NSF grants CCF-1116590 and CCF-1117241

12:51PM B50.00009 Emergence by Design in Artificial Spin Ice, CRISTIANO NISOLI, LANL, MUIR MORRISON, Caltech, GIA-WEI CHERN, LANL, IAN GILBERT, University of Illinois Urbana Champaign, SHENG ZHANG, ANL, PETER SCHIFFER, University of Illinois Urbana Champaign — Recently a new perspective has opened in the study of frustration through the creation of artificial frustrated magnetic systems [1,2]. These materials consist of arrays of lithographically fabricated single-domain ferromagnetic nanostructures that behave like giant Ising spins, whose interactions can be controlled through appropriate choices of their geometric properties and arrangement on a (frustrated) lattice. Higher control, inclusive of genuine thermal ensembles [3-5] have replaced the earlier and coarser methods based on magnetic agitation. Dynamical versions are now being realized [4,5], characterized in real time via PEEM, revealing statistical mechanics in action. This affords implementation of new geometries [6-8], not found in nature, for dedicated bottom up design of desired emergent properties [8]. Born as a scientific toy to investigate frustration-by-design, artificial spin ice might now be used to open “a path into an uncharted territory, a landscape of advanced functional materials in which topological effects on physical properties can be explored and harnessed.”

1:03PM B50.00010 Large-Scale Quantization and consequences in statistical mechanics. GEORGE LIVADIOTIS, Southwest Research Institute, USA — Recent developments revealed the existence of a new quantization constant \( h_{\bar{\text{L}}} \), similar to the Planck constant \( h \), but \( \sim 12 \) orders of magnitude larger. Planck’s constant constitutes the smallest possible phase-space parcel for individual and uncorrelated particles, while the new quantization constant describes the smallest possible phase-space parcel for collisionless particle systems characterized by collective behavior and local correlations. The majority of space plasmas throughout the heliosphere are such systems, but any other type of systems exhibiting collective behavior and correlations can be characterized by the large-scale quantization. Here, we discuss the consequences of this alternative phase-space scale to statistical mechanics. The generalization of the old-known Sackur-Tetrode entropic formulation for systems with local correlation is such an example.

1:15PM B50.00011 Modeling the thermal conductivity and shear viscosity of mixtures of methane and n-decane under high pressure and high temperature conditions using molecular simulations. JOHN SHELTON, Carnegie Mellon Univ — Atomistic molecular dynamics simulations were carried out at equilibrium to calculate the shear viscosity and thermal conductivity of various mixtures of methane and n-decane within the range of ambient to extreme temperature and pressure conditions (i.e. up to 500 degree F and 35,000 psi). Both a computationally efficient united-atom force field and an all-atom force field were employed in this investigation. A quantitative comparison of the results was performed against experimental values and values predicted from a high temperature - high pressure perturbed chain - statistically associated fluid theory (HPHT PC-SAFT) model. Analysis of the intermolecular structure of the fluid as well as its dynamical characteristics were performed.

1:27PM B50.00012 Simultaneous determination of the free energy profile and effective dynamics along a reaction coordinate1, JIONG ZHANG, IOAN KOSZTIN, University of Missouri-Columbia — Often one can gain insight into the functioning of a biomolecular system by following its dynamics along a relevant reaction coordinate (RC). A proper description of the motion along the RC requires not only the determination of the corresponding free energy profile (PMF) but also the correct identification of the underlying stochastic model. While there exist several methods for determining the PMF from fast non-equilibrium pulling processes, for simplicity it is implicitly assumed that the dynamics along the RC is a simple overdamped Brownian motion with known diffusion coefficient. However, in general, the dynamics along the RC is non-Markovian that can be modeled with a generalized Langevin equation characterized by a friction memory kernel. Here we propose and demonstrate a method that permits the simultaneous determination of both PMF and friction memory kernel from fast bi-directional (forward and time-reversed) pulling processes. As a result, one can determine whether the diffusion along the RC is normal or anomalous (e.g., subdiffusion). The proposed method provides a novel approach for identifying and characterizing the effective dynamics along a RC of a biomolecular system studied by either single-molecule force microscopy or steered molecular dynamics simulations.

1:39PM B50.00013 Unleashing the Power of Microcanonical Inflection-Point Analysis: The Principle of Minimal Sensitivity1, KAI QI, MICHAEL BACHMANN, The Univ of Georgia — In analogy to the principle of minimal sensitivity proposed by Stevenson for perturbative approaches in quantum field theory [1], we generalize microcanonical inflection-point analysis [2] by probing higher-order derivatives of the inverse temperature \( \beta(E) \) for signals of transitions in finite complex systems [3]. To illustrate the power of this analysis, we investigate adsorption properties of a simple-cubic lattice polymer model. The pseudophase diagram based on microcanonical inflection-point analysis is constructed. This example confirms the general potential of microcanonical statistical analysis for studies of pseudophase transitions for systems of finite size.


1Supported by NSF Grant DMR-1207437

1:51PM B50.00014 Optimisation by hierarchical search, ILIA ZINTCHENKO, ETH Zurich, MATTHEW HASTINGS, Microsoft Research, MATTHIAS TROYER, ETH Zurich — Finding optimal values for a set of variables relative to a cost function gives rise to some of the hardest problems in physics, computer science and applied mathematics. Although often very simple in their formulation, these problems have a complex cost function landscape which prevents currently known algorithms from efficiently finding the global optimum. Countless techniques have been proposed to partially circumvent this problem, but an efficient method is yet to be found. We present a heuristic, general purpose approach to potentially improve the performance of conventional algorithms or special purpose hardware devices by optimising groups of variables in a hierarchical way. We apply this approach to problems in combinatorial optimisation, machine learning and other fields.


11:15AM B51.00001 Exploiting disorder for global response: Independence of bond-level response and selected-bond removal networks1, SIDNEY R. NAGEL, The University of Chicago — The properties of amorphous solids near jamming are qualitatively different from those of simple crystals [1]. In a crystal with only one atom per unit cell, all atoms play the same role in producing the solid’s global response to an external perturbation; disordered materials are not similarly constrained. We will demonstrate a new principle that emerges for disordered matter: independence of bond-level response. This independence refers not only to the dearth of strong correlations between the response of one bond compared to another, but also, and more importantly, to the variation of response of any specific bond to different external perturbations. Using selected-bond removal networks, where individual bonds can be successively removed, we demonstrate that one can drive the overall system to different regimes of behavior. Consequently one can exploit disorder to achieve unique, varied, textured and tunable global response.


1Work done in collaboration with Carl P. Goodrich and Andrea J. Liu. Research supported by the US Department of Energy, Office of Basic Energy Sciences, Division of Materials Sciences and Engineering.
A theoretical framework forjamming in confluent biological tissues

M. LISA MANNING, Syracuse University — For important biological functions such as wound healing, embryonic development, and cancer tumorogenesis, cells must initially rearrange and move over relatively large distances, like a liquid. Subsequently, these same tissues must undergo buckling and support shear stresses, like a solid. Our work suggests that biological tissues can accommodate these disparate requirements because the tissues are close to glass or jamming transition. Recent self propelled particle models generically predict a glass/jamming transition that is driven by packing density $\varphi$ and happens at some critical $\varphi_{c}$ that is less than unity, many biological tissues that are confluent with no gaps between cells appear to undergo a jamming transition at a constant density ($\varphi = 1$). We suspect that the latter mimic inhomogeneous and anisotropic Cosserat metamaterial distributions. We review our experiments on mechanical metamaterials for cloaking. This includes two-dimensional graded laminate elastic metamaterials for broadband cloaking inpetrochemical emulsions, or protein solutions) or as reagents react (e.g. during interfacial polymerization reactions). In addition to probing the heterogeneity and mechanical properties of such evolving interfaces, we have developed techniques to visualize the evolution of bulk concentration fields as such reactions proceed, yielding new capabilities to probe reacting and evolving interfaces.

11:51 AM B51.00002

A theoretical framework for jamming in confluent biological tissues

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While recent self propelled particle models generically predict a glass/jamming transition that is driven by packing density $\varphi$ and happens at some critical $\varphi_{c}$ that is less than unity, many biological tissues that are confluent with no gaps between cells appear to undergo a jamming transition at a constant density ($\varphi = 1$). We will discuss a new theoretical framework for predicting energy barriers and rates of cell migration in 2D tissue monolayers, and show that this model predicts a novel type of rigidity transition, which takes place at constant $\varphi = 1$ and depends only on single cell properties such as cell-cell adhesion, cortical tension and cell elasticity. This model additionally predicts that an experimentally observable parameter, the ratio between a cell’s perimeter and the square root of its cross-sectional area, attains a specific, critical value at the jamming transition. We show that this prediction is precisely realized in primary epithelial cultures from human patients, with implications for asthma pathology.

12:27 PM B51.00003

Arboreal solutions: diodes, pumps, and diggers inspired by trees

ANETTE HOSENG, Massachusetts Institute of Technology — Many natural systems have evolved to perform certain tasks – climbing, sensing, swimming – as perfectly as possible within the limits set by the laws of physics. This observation can be used both to guide engineering design, and to gain insights into the form and function of biological systems. In this talk we will consider both of these themes in the context of trees. Beginning with the roots, we examine the role of flexibility in moving through granular substrates. Next we discuss fluid transport in tall plants and finally we apply our findings to the design of engineered solid state pumps and diodes.

*This work was partially funded by DARPA’s Maximum Mobility and Manipulation (M3) Program*
4:18PM D44.00004 Performance through Deformation and Instability, KATIA BERTOLDI, SEAS, Harvard University — Materials capable of undergoing large deformations like elastomers and gels are ubiquitous in daily life and nature. An exciting field of engineering is emerging that uses these compliant materials to design active devices, such as actuators, adaptive optical systems and self-regulating fluids. Compliant structures may significantly change their architecture in response to diverse stimuli. When excessive deformation is applied, they may eventually become unstable. Traditionally, mechanical instabilities have been viewed as an inconvenience, with research focusing on how to avoid them. Here, I will demonstrate that these instabilities can be exploited to design materials with novel, switchable functionalities. The abrupt changes introduced into the architecture of soft materials by instabilities will be used to change their shape in a sudden, but controlled manner. Possible and exciting applications include materials with unusual properties such negative Poisson’s ratio, phononic crystals with tunable low-frequency acoustic band gaps and reversible encapsulation systems.

4:54PM D44.00005 Programmable and Frustrated Mechanical Metamaterials, MARTIN VAN HECKE, Huygens-Kamerlingh Onnes Lab, Leiden University, the Netherlands, and FOM-Institute Amolf, Amsterdam, the Netherlands — Most metamaterials to date consist of periodic lattices of unit cells that work together in harmony. Here we demonstrate how frustration leads to new functionality. First we discuss 2D mechanical metamaterials whose response to uniaxial compression can be programmed by lateral confinement, allowing monotonic, nonmonotonic, and hysteretic behavior. These functionalities arise from a broken rotational symmetry which causes a highly nonlinear competition between two mutually incompatible modes of deformation. Second we show how to create non-periodic 3D metamaterials, leading to a wealth of novel functionalities, including mechanical pattern recognition. By perturbing the stacking order in these material we incorporate frustration which leads to multistable behavior.

Monday, March 2, 2015 2:30PM - 4:54PM —
Session D50 GSOFT GSNP: Focus Session: Dynamic Jamming Fronts and Shear Thickening
218 - Eric Brown, Yale University

2:30PM D50.00001 Shear thickening and S-shaped flow curves, ROMAIN MARI, Levich Institute, CCNY, RYOHEI SETO, Levich Institute, CCNY / Okinawa Institute of Science and Technology, JEFFREY F. MORRIS, MORTON M. DENN, Levich Institute and Department of Chemical Engineering, CCNY — The discontinuous shear thickening (DST) of dense suspensions is a remarkable phenomenon in which the viscosity can increase by several orders of magnitude at a critical shear rate. It follows the phenomenology of a first order transition between two “states” that we have recently identified as Stokes flows with lubricated or frictional contacts, respectively. Here we extend the analogy further and show the existence of a non-monotonic steady state flow curve by means of stress-controlled simulations, analogous to a non-monotonic equation of state. While we associate DST to an S-shape flow curve, at volume fractions above the shear jamming transition the frictional state loses flowability and the flow curve reduces to an arch, permitting the system to flow only at small stresses. Whereas a thermodynamic transition leads to phase separation in the coexistence region, we observe a uniform shear flow all along the thickening transition. A stability analysis suggests that uniform shear may be mechanically stable for the small Reynolds numbers and system sizes in a rheometer.

2:42PM D50.00002 Sedimentation of athermal particles in clay suspensions\(^1\), XAVIER CLOTET, ARSHAD KUDROLLI, Department of Physics, Clark University — We discuss sedimentation of athermal particles in dense clay suspensions which appear liquid-like to glass-like. These studies are motivated by the physics important to a diverse range of problems including remediation of oil sands after the extraction of hydrocarbons, and formation of filter cakes in bore wells. We approach this problem by first considering collective sedimentation of athermal spherical particles in a viscous liquid in quasi-two dimensional and three dimensional containers. We examine the system using optical and x-ray tomography techniques which gives particle level information besides global information on the evolution of the volume fraction. Unlike sediments in the dilute limit — which can be modeled as isolated particles that sediment with a constant velocity and slow down exponentially as they approach the bottom of the container — we find interaction between the particles through the viscous fluids leads to qualitatively different. We find significant avalanching behavior and cooperative motion as the grains collectively settle, and non-exponential increase in settling time. We discuss the effect of stirring caused by the sedimenting particles on their viscosity and consequently the sedimentation rates as a function of particle concentration.

\(^1\)Supported by Petroleum Research Fund Grant PRF # 54045-N9.

2:54PM D50.00003 Dynamic jamming fronts in iceberg-choked fjords, IVO PETERS, University of Chicago, JASON AMUNDSON, University of Alaska Southeast, RYAN CASSOTTO, University of New Hampshire, MARK FAHNESTOCK, University of Alaska Fairbanks, KRISTOPHER DARNELL, University of Texas Austin, MARTIN TRUFFER, University of Alaska Fairbanks, WENDY ZHANG, University of Chicago — During summertime at the glacier terminus at Jakobshavn Isbrae, Greenland, calving events are followed by rapid motion in the ice mélangé in front of the terminus. Understanding the dynamics of ice mélange is important because it acts as a resisting force to calving events. We analyze this motion using time-lapse photography and terrestrial radar images. Large calving events last for approximately 5 minutes, during which \(10^{14}\) J of potential energy is released. Motion in the ice mélangé quickly spreads out over at least 16 km down the fjord, and relaxes in about 1 hour. The ice mélangé can be viewed as a dense granular system, which is packed close to the jamming point. A jammed ice mélange resists expansion of the glacier terminus much more strongly and reduces iceberg calving, which may therefore play a significant role in glacier evolution. In our images, we observe dynamic jamming fronts, which propagate one order of magnitude faster than the instantaneous speed of the calving iceberg. From the ratio between the speed of the front and the calving iceberg we calculate a compaction that agrees with estimated compaction that we observe directly.

3:06PM D50.00004 Jamming under rapid pulling in dense granular suspensions\(^1\), SAYANTAN MA-JUMBAR, IVO R. PETERS, HEINRICH JAEGGER, MRSEC and the James Franck Institute, University of Chicago, IL 60637 — It requires a lot of force to quickly pull out an object immersed in a bath of dense granular suspension like corn starch in water. To understand such striking force response, we experimentally measure the normal force required for pulling out a cylindrical rod vertically from the suspension at a controlled pulling velocity. We observe that for slow pulling velocities the force response is similar to that of highly viscous fluids but above a certain threshold velocity the force show a diverging behavior soon after the initial viscous-like response. The time delay between the initial viscous-like and the diverging force response crucially depends on the proximity of the container walls from the initial contact region of the pulling rod with the suspension. We use in-situ X-ray radiography techniques to map out the local velocity profiles inside the suspension using metallic tracer particles which reveals that the force divergence takes place under pulling when the motion inside the suspension extends up to the container walls. Although the exact mechanism remains to be explained, our experiments suggest that both the magnitude and the delay in force response under pulling are reminiscent of dynamic jamming under impact in dense granular suspensions.

\(^1\)S.M. acknowledges support from a Kadanoff-Rice Post Doctoral fellowship from MRSEC, University of Chicago
3:18PM D50.00005 Stress fluctuations in dense granular suspensions, Qin Xu, Heinrich Jaeger, Department of Physics and James Frank Institute, University of Chicago — We experimentally investigate the temporal stress response during steady state shear in dense granular (non-Brownian) suspensions, where the solvent viscosity is varied to tune the frictional and viscous interactions in the system. We focus on the limit where packing fraction is close to the jamming point. For low viscosity suspending liquids, we show that, in the shear thickening regime, shear and normal stresses are highly coupled and exhibit significant fluctuations with time. As shear rate increases, the stress distributions evolve from Gamma to Gaussian distributions by contrast. In highly viscous solvents, stress fluctuations are greatly reduced and only show Gaussian distributions at different shear rates. Moreover, the fluctuation behaviors are associated with various relaxation modes of the system and therefore lead to different scalings of the power spectral density. By combining the fluctuation analysis in different regimes, we quantitatively show how the interactions between grains affect the suspension dynamics and provide a explanation of why shear thickening becomes weaker in highly viscous solvent.

3:30PM D50.00006 Dynamics of Concentrated Silica Suspension under Oscillatory Shear Studied by SAXS and XPCS, Jonghun Lee, Xiaomin Lin, Alec Sandy, Suresh Narayanan, Argonne National Laboratory, X-ray Science Division, Argonne National Laboratory, Center for Nanomaterials Team — The viscoelastic properties of complex fluids are often obtained by applying small amplitude oscillatory shear (SAOS). In this regime, their microstructure does not change by shear, and the shear stress linearly responds to the applied strain. However, in the real application, high shear strain or rate is applied, where the viscoelastic properties are affected by the microstructural deformation by this high shear. Here, we studied the dynamics of the concentrated silica nanoparticle suspensions in PEG under different shear strain regimes using small angle x-ray scattering (SAXS) and x-ray photon correlation spectroscopy (XPCS). With strain increasing, these suspensions showed shear thinning and shear thickening behavior, and their microstructural change was observed by SAXS. In oscillatory shear, as the original scattering volume periodically comes back to the original position, we could better study the changes in autocorrelation function by shear and diffusion than steady shear study where correlation decays by transit.

3:42PM D50.00007 Discontinuous shear thickening for frictional granular particles, Matthias Grob, Claus Heussinger, Annette Zippelius, Institute for Theoretical Physics, Goettingen University — We study the rheology of frictional granular particles with analytical modelling and numerical simulations in two dimensions. We derive a phase diagram with a topology different from the well known Liu-Nagel phase diagram for frictionless particles with a zero stress critical point. In contrast to the frictionless scenario, jamming first occurs at finite stress at a critical packing fraction \( \phi_c \) while a finite yield stress emerges only at \( \phi_y > \phi_c \). Remarkably, the flow is reentrant and we observe discontinuous shear thickening in the flow curves for \( \phi \in (\phi_c, \phi_y) \) with \( \phi_y > \phi_c \). All these features can be rationalized with a simple constitutive equation which contains the frictionless scenario as a limiting case.

3:54PM D50.00008 Material properties of the shear-thickened state in concentrated near-hard-sphere colloidal dispersions, Norman Wagner, Colin Cwalina, Chemical and Biomolecular Engineering, University of Delaware — Reversible shear thickening is common in concentrated dispersions of Brownian hard-spheres at high shear rates. We confirm the existence of a well-defined colloidal shear-thickened state through experimental measurements of the shear stress and the first and second normal stress differences in the shear-thickened state as a function of the particle volume fraction for a model dispersion of near-hard-spheres. The shear stress and normal stress differences are observed to grow linearly with the shear rate in the shear-thickened state and both normal stress differences are observed to be negative. Our experimental results show that perturbations of a colloidal dispersion can be understood by three material properties: the shear viscosity and first and second normal stress difference coefficients— that are a function of the volume fraction. All three material properties are found to diverge with a power law scaling with the approach to maximum packing, which is found to be 0.54 \pm 0.01. We find the magnitude of the relative shear viscosity is greater than the magnitude of the dimensionless second normal stress difference, which is greater than the magnitude of the dimensionless first normal stress difference. These results are consistent with the theoretical predictions for shear thickening by hydrocluster formation and quantitatively comparable to Stokesian Dynamics simulations. We further postulate and show that these material properties are consistent with those measured for non-Brownian suspensions.

4:06PM D50.00009 The reciprocal effect of lubrication and contact forces in shear-thickening of colloidal suspensions, Safa Jamali, Arman Boromand, Joao Maia, Case Western Reserve Univ — Recently, the shear-thickening of colloidal suspensions at high shear rates in general, and the so-called discontinuous shear-thickening (DST) in particular, has been attributed to frictional contact forces at high shear rates. This emerging understanding of the contact forces in a suspension has brought back the well-known dilatancy theory which was rather dormant in the past two decades. Here, we study the necessity of short-range hydrodynamics and the correlation between the contact and lubrication forces in shear-thickening suspensions. We use a modified Dissipative Particle Dynamics method that includes squeeze mode lubrication potentials based on the pair drag between two interacting colloids. The effect of simulation parameters and contact potentials on the rheological response of a suspension is studied. Our results show that although the quality of the shear-thickening behavior (whether DST can be obtained or not) is dominated by the contact potentials, the lubrication force is a prerequisite for any type of shear-thickening to be recovered. Needless to mention that this argument is valid for the high Pécllet numbers, as opposed to shear-thinning regime which can be fully reproduced without the need to lubrication or contact potentials.

4:18PM D50.00010 Dynamic jamming under impact in shear thickening suspensions, Shomeek Mukhopadhyay, Yale University — Shear thickening fluids such as cornstarch and water show remarkable impact response allowing, for example, a person to run on the surface. We perform constant velocity impact experiments and imaging in shear thickening fluids at velocities lower than 500 mm/s and suspension heights of a few cm. In this regime where inertial effects are insignificant, we find that fronts with a dynamically jammed (DJ) region behind it are generated under impact. When this front and the DJ region reaches the opposite boundary it is able to support large stresses like a solid. These stresses are sufficient to support the weight of a running person. In addition we find a shear thickening transition under impact due to collision of the fronts with the boundary. There is a critical velocity required to generate these impact activated fronts. Using the observations on fronts, DJ region and using energy balance arguments we construct a model to explain the phenomena of running on the surface of cornstarch suspensions. The model shows quantitative agreement with our measurements using high-speed video of running on cornstarch and water suspensions.

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1Supported by NSF DMR 1410157
Yanking a chain: Lift-off and snapping

Pierre-Thomas Brun, MIT, Basile Audoly, UPNC/CNRS, Alain Goriely, Dominic Vella, University of Oxford — We revisit the first mechanics problem that everyone meets in high school: a chain on a frictionless pulley. Rather than considering the problem of a mass on at each end of the string, however, we suppose that one end is subject to a constant acceleration. This simple change has some dramatic consequences for the ensuing motion: the chain “lifts off” from the pulley, the free end accelerates faster than the end that is being pulled and finally the chain undergoes a dramatic reversal of curvature reminiscent of the crack or snap of a whip. We present simple experiments, numerical simulations and theoretical arguments that explain some but not all of these phenomena.

Unraveling the chain fountain

John Biggins, Mark Warner, University of Cambridge — If a chain is initially at rest in a beaker at a height \( h_1 \) above the ground, and the end of the chain is pulled over the rim of the beaker and down towards the ground and then released, the chain will spontaneously “flow” out of the beaker under gravity. Furthermore, the beads do not simply drag over the edge of the beaker but form a fountain reaching a height \( h_2 \) above it. I will show that the formation of a fountain requires that the beads come into motion not only by being pulled upwards by the part of the chain immediately above the pile, but also by being pushed upwards by an unexpected reaction force from the pile of stationary chain. I will propose possible origins for this force, argue that its magnitude will be proportional to the square of the chain velocity, and predict and verify experimentally that \( h_2 \propto h_1 \). I will also discuss the case where the pot is tilted, and show, experimentally and theoretically, that the chain rises and falls in an inverted catenary, and discuss the appropriate boundary conditions at the ends of the chain.

Jumping, snapping and popping at nanometer scale

David Haviland, Royal Institute of Technology — The “jump-to-contact” instability is well known in Atomic Force Microscopy. When a tip attached to a soft cantilever approaches a surface, the large attractive force gradient disrupts the quasi-static force balance and the tip snaps in to contact with the surface. Less appreciated is the converse instability, where a soft liquid-like polymer surface jumps to meet the tip. This nano-scale pop is inaudible, but it does leave a distinctive signature if one carefully monitors the cantilever’s steady state dynamics when driven with multiple tones. The nonlinear tip-surface interaction causes intermodulation, or frequency mixing of the drive tones. When many intermodulation products are measured close to the cantilever resonance the spectrum can be transformed to reveal the in-phase and quadrature forces acting on the tip, as a function of oscillation amplitude. We present experimental measurements and theoretical modelling that reveal this surface-jump-to-tip instability.

TBD

Keith Seffen, Cambridge University, UK — No abstract available.

The chocolate-egg problem: Fabrication of thin elastic shells through coating

Anna Lee, Joel Marthelet, Pierre-Thomas Brun, Pedro Reis, Massachusetts Institute of Technology — We study the fabrication of thin polymeric shells based on the coating of a curved surface with a viscous fluid. Upon polymerization of the resulting thin film, a slender solid structure is delivered after demolding. This technique is extensively used, empirically, in manufacturing, where it is known as rotational molding, as well as in the food industry, e.g. for chocolate-eggs. This problem is analogous to the Landau-Levich-Derjaguin coating of plates and fibers and Breatheron’s problem of film deposition in cylindrical channels, albeit now on a double-curved geometry. Here, the balance between gravity, viscosity, surface tension and polymerization rate can yield a constant thickness film. We seek to identify the physical ingredients that govern the final film thickness and its profile. In our experiments using organosilicon, we systematically vary the properties of the fluid, as well as the curvature of the substrate onto which the film is coated, and characterize the final thickness profile of the shells. A reduced model is developed to rationalize the process.

Folding of non-Euclidean curved shells

Nakul Bendre, Arthur Evans, University of Massachusetts Amherst, Sarah Innes-Gold, Tufts University, Luis Marin, University of Massachusetts Amherst, Itai Cohen, Cornell University, Christian Santangelo, Ryan Hayward, University of Massachusetts Amherst — Origami-based folding of 2D sheets has been of recent interest for a variety of applications ranging from deployable structures to self-folding robots. Though folding of planar sheets follows well-established principles, folding of curved shells involves an added level of complexity due to the inherent influence of curvature on mechanics. In this study, we use principles from differential geometry and thin shell mechanics to establish fundamental rules that govern folding of prototypical creased shells. In particular, we show how the normal curvature of a crease line controls whether the deformation is smooth or discontinuous, and investigate the influence of shell thickness and boundary conditions. We show that snap-folding of shells provides a route to rapid actuation on time-scales dictated by the speed of sound. The simple geometric design principles developed can be applied at any length-scale, offering potential for bio-inspired soft actuators for tunable optics, microfluidics, and robotics.

This work was funded by the National Foundation through EFRI ODISSEI-1240441 with additional support to S.I.-G. through the UMass MRSEC DMR-0820506 REU program.

Curvature-induced symmetry breaking selects elastic wrinkling patterns

Norbert Stoop, Romain Lagrange, Denis Terwagne, Pedro Reis, Joern Dunkel, Massachusetts Institute of Technology — Wrinkling in curved bilayer surfaces is a ubiquitous phenomenon, including embryogenesis, biological tissue differentiation or structure formation in heterogeneous thin films. Due to curved substrate and the strong nonlinearities in the elastic strains, predictions for the wrinkling morphology are notoriously difficult to obtain using classical analysis. Here, we derive a generalized Swift-Hohenberg theory to describe these morphologies and their pattern selection. Testing the theory against experiments on spherically shaped surfaces, we find quantitative agreement with analytical predictions for the phase transition curves separating labyrinth, hybrid and hexagonal wrinkling phases. Our approach builds on general differential-geometric principles and can be extended to arbitrarily shaped surfaces.

Bi-stable characteristics of thick-walled domes with applications to soft material snapping

Amit Madhukar, UIUC — Bi-stable structures can exhibit interesting mechanical properties which makes them the focus of research in the field of extreme mechanics. Fast transitions can occur between equilibrium states with very little actuation force. One such bi-stable structure is the thick-walled dome. In this work, we apply finite element techniques to examine the stability of such spherical, thick-walled domes undergoing large deformation. We apply the following methods to two structures: a single-layered system as well as bi-layered colloidal microparticles which actuate through pH driven mismatched swelling. The presence of a metastable state is identified by the energy characteristics alone. Monotonically increasing energy represents a mono-stable structure. Bi-stability occurs when we achieve a local energy minimum at some nonzero displacement. Of more interest is the region near the transition of these states where we find a so called pseudo-bi-stable state where small perturbations result in fast transition from the elevated energy state, or snapping. We use our simulations to map out the critical geometric parameters that govern this behavior in order to design a dome to snap. Experimental results are used to validate the simulation results.
10:00AM F44.00009 Morphing and Snapping of Plates and Shells via Swelling, DOUGLAS HOLMES, Boston University. MATTEO PEZZULLA, PADLA NARDINOCCHI, Università degli Studi di Roma “La Sapienza”, STEVEN SHILLIG, Virginia Tech — Non-homogenous swelling will induce curvature within thin structures - beams will bend and plates will morph into shells. In this work, we examine the dynamics of swelling plates as they deform into shells with either positive or negative Gaussian curvature. The swelling process is driven by a concentration gradient between two partially swollen structures, and the curvature of the final shell is dictated by the geometric arrangement of the swelling materials. The dynamics of this process are driven by diffusion and the geometry of the contact line. We demonstrate that these dynamic deformations can occur over a much faster timescale if the structure is confined. Beginning with a beam bent into an arch, we show how this swelling leads to a snap-through instability with dynamics similar to an arch compressed by a point load. The swelling-induced morphing presented in this talk provides a very simple and controllable way to achieve complex shell structures from simple building blocks.

10:12AM F44.00010 Interface adhesion between 2D materials and elastomers measured by buckle delamination, CHRISTOPHER BRENNAN, NANSHU LU, Univ of Texas, Austin — A major application for 2D materials is creating electronic devices, including flexible and wearable devices. These applications require complicated fabrication processes where 2D materials are either mechanically exfoliated or grown via chemical vapor deposition and then transferred to a host substrate. Both processes require intimate knowledge of the interactions between the 2D material and the substrate to allow for a controllable transfer. Although adhesion between 2D materials and stiff substrates such as silicon and copper have been measured by bulge or peeling tests, adhesion between 2D materials and soft polymer substrates is hard to measure by conventional methods. Here we propose a simple way of measuring the adhesion between 2D materials and soft, stretchable elastomers using mature continuum mechanics equations. By creating buckle delamination in 2D atomic layers and measuring the buckle profile using an atomic force microscope, we can readily extract 2D-elastomer adhesion energy. Here we look at the adhesion of MoS2 and graphene to PDMS. The measured adhesion values are found insensitive to the applied strains in the substrate and are one order smaller than 2D-silicon oxide adhesion which is mainly attributed substrate surface roughness differences.

10:24AM F44.00011 Harnessing snap-through instability for shape-recoverable energy-absorbing structure, SUNG KANG, SICONG SHAN, JORDAN RANNEY, PAI WANG, FRANCISCO CANDIDO, JENNIFER LEWIS, KATIA BERTOLDI, Harvard Univ — Energy absorbing materials and structures are used in numerous areas for maintaining structural integrity, protection and comfort. To absorb/dissipate energy from shock/vibration, one generally relies on processes such as plastic deformation and damping as the case of metal foams and suspensions. Because plastic deformation and damping induce irreversible change in the energy-absorbing systems such as shape changes and degradation of damping elements by heat dissipation, it would be desirable to develop a new energy-absorption mechanism with reversibility. Furthermore, it would be desirable to implement energy-absorption mechanisms whose behavior is not affected by the rate of loading. Here, we report a shape-recoverable system that absorbs energy without degradation by harnessing multistability in elastic structures. Using numerical simulations, we investigate geometrical parameters that determine the onset of the snap-through and multi-stability. We subsequently manufacture structures with different geometrical parameters and sizes using a scalable direct-write 3D printing approach. We experimentally demonstrate reversible energy-absorption in these structures at strain rates over three orders of magnitudes, with reduced peak acceleration under impact by up to one order of magnitude compared with control samples. Our findings can open new opportunities for scalable design and manufacturing of energy-absorbing materials and structures.

10:36AM F44.00012 Non-porous Elastic Sheets with Negative Poisson’s Ratio, FARHAD JAVID, School of Engineering and Applied Science, Harvard University, EVELYNE SMITH-ROBERGE, Department of Mathematics and Statistics, McGill University, MATTHEW INNES, ALI SHANIAN, Rolls-Royce Energy, KATIA BERTOLDI, School of Engineering and Applied Science, Harvard University, HARVARD UNIVERSITY COLLABORATION, ROLLS-ROYCE ENERGY COLLABORATION — Negative Poisson’s ratio (NPR) materials—materials that contract (expand) in transverse directions when compressed (stretched) uniaxially—have attracted significant interest both because of their unusual properties and their many potential applications. However, complex fabrication processes, high porosity, and low structural stiffness of most of the proposed NPR materials have significantly limited their practical applications. In this work, a novel NPR material is designed by coupling the in- and out-of-plane (popping) deformations in an elastic sheet with a periodic distribution of dimples. As a result, such NPR material has zero porosity, relatively high structural stiffness, and can be made from both hard and soft materials using industrial fabrication techniques.

10:48AM F44.00013 Elastic and capillary failure of particle stabilized droplets, NIVEDITHA SAMUDRALA, RAPHAEL SARFATI, JIN NAM, ERIC DUFRESNE, None — Colloidal surfactants robustly stabilize fluid interfaces against spontaneous phase separation. Like molecular surfactants, they improve the thermodynamic and kinetic stability of the interface. However, particle stabilized interfaces are also thought to exhibit enhanced mechanical stability. Here, we investigate the mechanics of colloid-stabilized droplets using micro-pipette aspiration. We observe two distinct modes of failure: a classic buckling of the particle-laden interface similar to the buckling of a thin elastic shell, and a capillary failure where the encapsulated fluid is sucked out through the porous shell. To elucidate the underlying physics, we quantify the critical tension to drive each of these phenomena as a function of the size of the droplets, particles, and micro-pipette.

Tuesday, March 3, 2015 8:00AM - 10:48AM –
Session F45 GSNP: Focus Session: Systems far from Equilibrium I

8:00AM F45.00001 Thermodynamics with information flow: Applications to Maxwell demons and biochemical sensing, JORDAN HOROWITZ, University of Massachusetts at Boston — Information is often perceived as an immaterial entity. However, since the birth of statistical physics, it has been argued, based on thought experiments by the likes of Maxwell, that there are physical thermodynamic implications to information manipulation. In this talk, I will discuss a unified framework for the information transfers between continuously interacting systems, describing how information generated in an auxiliary system can be utilized by another as a fuel for an otherwise impossible process. Indeed, while the joint system satisfies the second law, the entropy balance of each system is modified by an information term related to the mutual information between the pair of systems. I will then show how this result incorporates the traditional analysis of Maxwell’s demon. In addition, I will use this framework to analyze the thermodynamics and energetics of biological sensory adaptation, employing the biochemical sensing network of E. Coli chemotaxis as a representative example.

8:36AM F45.00002 Efficiency and Large Deviations in Time-Asymmetric Stochastic Heat Engines, TODD GINGRICH, GRANT ROTSKOFF, University of California, Berkeley, SURIYANARAYANAN VAIKUNANTHAN, University of Chicago, PHILLIP GEISSLER, University of California, Berkeley — In a stochastic heat engine driven by a cyclic non-equilibrium protocol, fluctuations in work and heat give rise to a fluctuating efficiency. Using computer simulations and tools from large deviation theory, we have examined these fluctuations in detail for a model two-state engine. We find in general that the form of efficiency probability distributions is similar to those described by Verley et al. [2014 Nat Comm, 5 4721], in particular featuring a local minimum in the long-time limit. In contrast to the time-symmetric engine protocols studied previously, however, this minimum need not occur at the value characteristic of a reversible Carnot engine. Furthermore, while the local minimum may reside at the global minimum of a large deviation rate function, it does not generally correspond to the least likely efficiency measured over finite time.
9:00AM F45.00004 On the heat flux and entropy produced by thermal fluctuations, SERGIO CILIBERTO, ENSL-CNRS, ALBERTO IMPARATO, University of Aarhus — We study both experimentally and theoretically the statistical properties of the energy exchanged between a Brownian particle and two heat reservoirs. The energy flux is related to an isothermal expansion and compression process in a soft wall. This process qualitatively mimics that in a rigid wall and offers a valuable tool for extracting work from a system out of equilibrium.

9:12AM F45.00005 The thermodynamic geometry of the Ising model, GRANT ROTSKOFF, University of California, Berkeley, GAVIN CROOKS, Lawrence Berkeley National Laboratory — Biological machines have evolved to produce useful work in a finite time by operating out-of-equilibrium, but we do not know how evolution has guided the design of these machines: Are there generic design principles that direct motors towards higher efficiency? To answer this question, one must first calculate a finite-time efficiency, which poses a significant challenge — tools of equilibrium statistical mechanics fail to describe the relationship between a protocol and the efficiency of a machine subject to that protocol. Using a geometric framework, I will describe a procedure for predicting the protocol that minimizes the dissipated work during an irreversible process. My talk will focus on optimal control of the 2D Ising model; this example will provide strategies for employing geometric thermodynamics to models that cannot be solved analytically.

9:24AM F45.00006 Thermodynamic metric of nonequilibrium steady states, DIBYENDU MANDAL, Helen Wills Neuroscience Institute, University of California, Berkeley, CHRISTOPHER JARZYNSKI, Department of Chemistry and Biochemistry, and Institute for Physical Science and Technology, University of Maryland, College Park — Within the linear response regime, minimally dissipative transitions between equilibrium states are given by the geodesics of a thermodynamic metric in parameter space. We derive an analogous geometric structure for transitions between nonequilibrium steady states. Having a suitable renormalization of heat. With a novel expansion formula for the governing master equation, we propose an exact expansion formula for the governing master equation. Furthermore, we evaluate the fluctuating entropy, which satisfies a conservation law. These experimental results are fully justified by the theoretically analysis. Our results give more insight into the energy transfer in the famous Feynmann ratchet widely studied theoretically but never in an experiment. Starting from this example we also discuss the experimental results of the heat transfer between two Brownian particle kept at different temperature.

9:36AM F45.00007 Work fluctuations for a colloidal particle in a time-varying optical trap in analogy with gas in expansion and compression, HYUK KYU PAK, UNIST, DONGYUN LEE, Pusan National University, CHULAN KWON, Myeongji University — The fluctuation theorem provides a rigorous statistical rule for thermally fluctuating quantities such as work, heat, and entropy production in nonequilibrium thermodynamic processes. However, testing the theorem needs small systems where the fluctuations are more observable. Therefore, there are great difficulties in the experimental measurements. In this work, we investigate the motion of a colloidal particle trapped in a harmonic potential with time-varying stiffness. Here, we estimate the work done on the particle during compression and expansion by measuring its particle position in the first time. The resultant probability distributions of the work in both processes satisfy very well the Jarzynski equality and the Crooks fluctuation theorem. Because this isothermal expansion and compression process in a soft wall qualitatively mimics that in a rigid wall, it offers valuable tool for extracting work from micromechanical heat engines.

10:00AM F45.00009 Work Relations from Doi-Peliti Field Theory, ANDREW BAISH, BENJAMIN VOLLMAYR-LEE, Bucknell University — We develop a field-theoretic description of non-equilibrium work relations, using Doi-Peliti field theory. We consider classical particles on a lattice, with pair interactions and a local potential, coupled to a thermal bath. Work protocols are imposed by varying the local potential, which drives the system out of equilibrium. In this framework, work relations appear simply as the result of a gauge-like transformation.

10:12AM F45.00010 Experimental test of Generalized Flutuation Dissipation Theorems during a transient, SERGIO CILIBERTO, ISAAC THEUKAUFF, ARTYOM PETROSYAN, ENSL-CNRS — In recent years the study of the Fluctuation Dissipation Theorem (FDT) in out of equilibrium system have received a lot of attention both theoretically and experimentally. Several Generalized FDT (GFDT) have been proposed but many theoretical results concern the steady state regimes and only a few the transient regimes. We report here an experiment in which two formulations of GFDT have been tested during the relaxation dynamics of a liquid crystal quenched near the critical point of Fredericksz transition, which is similar to a second order phase transition and it presents a critical slowing down. Thus the relaxation dynamics after the quench is sufficiently slow to perform several measurements. During the relaxation, the equilibrium FDT is strongly violated and this allows us to test the two GFDT. One is based on a transient fluctuation theorem and the time dependent distribution function. The other is a generalization of the Hatano-Sasa relations for transient state and has the very clear interpretation that the violation of the equilibrium FDT is related to the heat fluxes. The advantages and draw back of the two GFDT are discussed from an experimental point of view.
10:24AM F45.00011 Nonequilibrium equalities in absolutely irreversible processes, YUTO MURASHITA, KEN FUNO, MASAHIRO UEDA, University of Tokyo — Nonequilibrium equalities have attracted considerable attention in the context of statistical mechanics and information thermodynamics. Integral nonequilibrium equalities reveal an ensemble property of the entropy production $\sigma$ as $\langle e^{-\sigma} \rangle = 1 - \lambda_S$. Although nonequilibrium equalities apply to rather general nonequilibrium situations, they break down in absolutely irreversible processes, where the forward-path probability vanishes and the entropy production diverges. We identify the mathematical origins of this inapplicability as the singularity of probability measure.

10:36AM F45.00012 Work Relations Connecting Nonequilibrium Steady States Without Detailed Balance, YING TANG, RUOSHI YUAN, PING AO, Shanghai Jiao Tong Univ — Bridging equilibrium and nonequilibrium statistical physics attracts sustained interest. Hallmarks of nonequilibrium systems include a breakdown of detailed balance, and an absence of a priori potential function corresponding to the Boltzmann-Gibbs distribution, without which classical equilibrium thermodynamical quantities could not be defined. Here, we construct dynamically the potential function through decomposing the system into a dissipative part and a conservative part. We then develop a nonequilibrium theory by defining thermodynamical quantities based on the potential function. We elucidate this procedure explicitly in a class of time-dependent linear diffusive systems without mathematical ambiguity. We also obtain the exact work distribution, and generalized work relations for the calculation of free energy difference between nonequilibrium steady states. Our results demonstrate that concepts for equilibrium can be naturally extended to nonequilibrium steady state, which provides a platform to study thermodynamics of systems without detailed balance.

Tuesday, March 3, 2015 8:00AM - 10:48AM
Session F49 GSOFT GSNP DFD: Focus Session: Wet Granular Matter 217D - Arshad Kudrolli, Clark University

8:00AM F49.00001 Wet sand flows better than dry sand, CHRISTIAN WAGNER, Saarland University — Wet sand that does not contain too much water is known to be stiff enough to build sand castles or in physical words has a significant yield stress. However, we could recently show that there are quite a few matters under which such wet sand opposes less resistant to flow than its dry counterpart. This effect might have been already known to the old Egyptians: The Ancient painting of El Bersheh at the tomb of Tehutihetep shows that there was liquid poured in front of the sledge that was used to transport heavy weight stones and statues. While archeologist have attributed this to a sacred ceremony, our data clearly show that wetting the sand ground drastically decreases the effective sliding friction coefficient. We first study the stress-strain behavior of sand with and without small amounts of liquid under steady and oscillatory shear. Using a technique to quasistatically push the sand through a tube with an enforced parabolic (Poiseuille-like) profile, we minimize the effect of avalanches and shear localization. We observe that the resistance against deformation of the wet (partially saturated) sand is much smaller than that of the dry sand, and that the latter dissipates more energy under flow. Second we show experimentally that the sliding friction on sand is greatly reduced by the addition of some—but not too much—water. The formation of capillary water bridges increases the shear modulus of the sand, which facilitates the sliding.

8:36AM F49.00002 Wet granular materials submitted to thermal cycling, GEOFFROY LUMAY, FRANCOIS LUDEWIG, University of Liege, JORGE FISCINA, Saarland University, MARYAM PAKPOUR, NICOLAS VANDEWALLE, STEPHANE DORBOLO, University of Liege — Many phenomenons observed in nature are related to the particular behavior of wet granular materials submitted to temperature cycling: ice-lens formation in soil leading to frost heaving, landslides, structures formation in permafrost, stone heave and possibly some geological formations observed on Mars. We present experimental results concerning the effect of thermal cycling on the packing fraction of equal spheres with the presence of water. First, the case corresponding to completely immersed granular piles is considered. Afterward, the effect of thermal cycling on unsaturated granular piles is discussed. The pile is submitted to temperature cycling ranging from $T_1$ to $T_2$. If the temperature is always higher than 4°C, the temperature increase (or decrease) induces a dilatation (or contraction) of the grains and of the water. We show that the packing fraction variation is mainly related to water dilation and contraction. If the temperature decreases under 0°C during a cycle, the water situated between the grains experiences a strong dilatation during the ice melting step and a contraction during the ice melting step. In this case, we show how the freeze-thaw transition affects the packing fraction of the pile.

8:48AM F49.00003 Mechanical Properties of Sheared Wet Granular Piles, RALF SEEMANN, MARC SCHABER, SOMNATH KARMAKAR, ANNA-LENA HIPPLER, Experimental Physics, Saarland University, 66041 Saarbruecken, Germany, MARIO SCHEL, MARCO DI MICHEL, European Synchrotron Radiation Facility, 6 Rue Jules Horowitz, 38000 Grenoble, France, MARTIN BRINKMANN, MPI for Dynamics and Self-Organisation, 37077 Goettingen, Germany — The mechanical properties of dry and wet granulates are explored when being sheared with a parabolic profile at constant shear volume. The dissipated energy increase linearly with external pressure both for a wet and a dry granulate. However, the dissipated energy for a wet granulate has a finite value for the limiting case of vanishing external pressure and increases slower with external pressure compared to the dry granulate. Using a down sized version of the shear cell the reorganization of a granulate and liquid is additionally imaged in real time using x-ray micro-tomography. With the insight from x-ray tomography the contribution of the breaking capillary bridges to the dissipated energy can be analyzed. We could also shed light on the influence of dilatation effects on the dissipated energy upon inverting the shear direction.

9:00AM F49.00004 The Effect Liquid Loading on the Rheology of Granular Flows, SANKARAN SUNDARESAN, ALI OZEL, YILE GU, Department of Chemical and Biological Engineering, Princeton University, Princeton, New Jersey 08540, USA, STEFAN RADL, Institute for Process and Particle Engineering, Graz University of Technology, Inffeldgasse 13/III, 8010 Graz, Austria, SUNDAR’S GROUP TEAM, CFDEM COLLABORATION — Discrete element simulations of simple shear flows of dense and homogeneous assemblies of uniform, spherical, soft and dry particles reveal three regimes: (i) a quasi-static regime, where the stress is independent of shear rate, (ii) an inertial regime where the stress varies quadratically with shear rate and (iii) an intermediate regime where the stress manifests power-law dependence with $n = 1/2$. Inclusion of inter-particle cohesion due to van der Waals force has been shown to lead to bifurcation of the inertial regime into two regimes: (a) a cohesive rate-independent regime and (b) an inertial regime. In the present study, we perform analogous simulations for wet particles. We account for capillary and viscous interaction forces between particles, which result from the liquid bridges, and allow for liquid transfer between the particles and the liquid bridge. It is found that the bifurcation of the inertial regime observed with van der Waals interaction persists for capillary cohesion and that the span of the cohesive rate-independent regime increases with liquid loading in the pendular regime. A simple model for steady shear rheology is obtained by blending the results in various regimes. The presentation will also discuss the effect liquid viscosity on the flow behavior.
9:12AM F49.00005 Shear bands at the Jamming Transition: The role of Weak Attractive Interactions

EHSAN IRANI, Institute for Theoretical Physics, Georg-August University of Göttingen, PINAKI CHAUDHURI, Institute of Mathematical Sciences, Tamil Nadu, India, CLAUS HEUSINGER, Institute for Theoretical Physics, Georg-August University of Göttingen — We study the rheology of a particulate system close to jamming in the presence of weakly attractive interactions. Lees-Edwards boundary conditions are used to simulate a shear-controlled flow. In addition to Bagnold scaling at large shear rates, the attraction results in a finite yield stress in the limit of small shear rates. In the yield regime a fragile solid is formed and the rheology can be explained by a scaling argument that exploits the vicinity to the isostatic state. In the transition region the shear stress develops a null region, which in large enough systems leads to flow of independent shear bands. These features are rationalized by a scenario that involves the competition between attraction-induced structure formation and its break-down because of shearing. Properties of shear bands are studied in order to reveal the physical mechanisms that underly the non-monotonic flow curve and the flow heterogeneities in the transition region. This work may help to elucidate the origin of shear bands in different materials with finite and short-ranged attractive forces.

9:24AM F49.00006 Flow and clogging of submerged hoppers

JUHA KOIVISTO, DOUGLAS DURIAN, University of Pennsylvania — The discharge rate for granular hoppers was recently found to depend on the filling height when the hopper is submerged in water\(^1\). This effect is further studied with an automated experimental setup consisting of cylindrical flat bottomed hoppers with various diameters and orifices. The grains are spherical glass beads of diameter 1.1 ± 0.1 mm. The flow rate is measured with an electric scale connected to a computer. With this, we confirm the counterintuitive surge in the flow rate as the filling height decreases toward zero. We also find a similar surge for dry gains, but the size of the effect is much smaller and to our knowledge is previously unseen. In both cases we notice that the flow of grains near the wall changes from creep like behavior to mass flow as the hopper diameter decreases. The hypothesis for the surge effect is changes in compatible stresses and force chains. To alter such behavior, on-going work includes changing the fluid pressure and flow rate near the orifice as well as changing the roughness of the walls. Work has also begun on clogging for small orifices in submerged hoppers, where preliminary observations show an exponential distribution of flow durations.

\(^1\) T.J. Wilson et al., Pap. Phys. 6, 060009 (2014).

9:36AM F49.00007 Armoring, stability, and transport driven by fluid flow over a granular bed

BENJAMIN ALLEN, ARSHAD KUDROLLI, Department of Physics, Clark University — We discuss experiments investigating the evolution of a granular bed by a fluid flow as a function of shear rate at the fluid-bed interface. This is a model system to investigate a variety of physical examples including wind blowing over sand, sediment transport in rivers, tidal flows interacting with beaches, flows in slurry pipelines, and sand proppants in hydraulic fracturing. In order to examine the onset and entrainment of the granular bed under steady state conditions, we have constructed a novel conical rheometer system which allows the choice of the amount of shear to be applied to the bed. The fluidization of the granular bed by the fluid flow is controlled by the gravitational, inertial, and fluid forces acting on the particles. The transition between bed load and fluid creep occurs at a critical value of the local shear rate, characterized by a critical dimensionless shear rate, the viscous number. We also characterize the important length and time scales for dynamical heterogeneities as a function of depth and find that grain dynamics are spatiotemporally heterogeneous at all depths. The dynamics slow down monotonically as a function of depth, but the domain size is largest at the transition to creeping. We propose a new phase diagram for fluid-sheared granular transport, where “bed load” sediment transport is defined as a dense granular flow driven by fluid shear from above and granular creep from below.

9:48AM F49.00008 Creep and Dynamical Heterogeneities of Fluid-Driven Granular Flows

CARLOS ORTIZ, MORGANE BOUSSAIS, DOUGLAS DURIAN, DOUGLAS JEROLMACK, Univ of Pennsylvania — Earth’s surface is a fluid-sediment interface evolving through fluid-driven granular flow. To probe long-time dynamics, we construct an annular chamber that mimics an infinitely-long river channel. We use non-Brownian, spherical plastic grains, fully submerged in a less dense index-matching fluid. We drive the packs with a laminar flow and record dynamics by laser scanned particle tracking. “Bed load” grains near the surface exhibit relatively fast shear. By long-time averaging grain trajectories, we find that grains deep in the pack, which appear frozen by eye, exhibit a slow creep dynamics. The transition between bed load and creep occurs at a critical value of the local relaxation time, characterized by a critical dimensionless shear rate, the viscous number. We also characterize the important length and time scales for dynamical heterogeneities as a function of depth and find that grain dynamics are spatiotemporally heterogeneous at all depths. The dynamics slow down monotonically as a function of depth, but the domain size is largest at the transition to creeping. We propose a new phase diagram for fluid-sheared granular transport, where “bed load” sediment transport is defined as a dense granular flow driven by fluid shear from above and granular creep from below.

10:00AM F49.00009 Onset and cessation of grain motion in riverbed erosion experiments

JULIA SALEVAN, ABE CLARK, JULIA SALEVAN, Yale University, MARK SHATTUCK, City College of New York, COREY O’HERN, NICHOLAS OUELLETTE, Yale University — Erosion due to fluid flow plays a principal role in shaping landscapes. However, the complexity of the coupling between hydrodynamic shear, sediment transport, and internal granular bed rearrangements limits our understanding of the particle-scale physics that governs erosion. In particular, it is unclear whether particle rearrangements in an immured bed are controlled largely by fluid forcing or by mechanical instabilities in the network of interparticle forces, and how the onset and cessation of particle motion is linked to the prior shear history of the bed. To address these questions, we perform experimental studies in a recirculating water flume in which we drive turbulent flow across beds of glass beads. We use optical imaging to characterize both the turbulence and dynamics of the bed, and we study the differences in flow properties required to initiate and maintain particle motion.

10:12AM F49.00010 Jamming and unjamming in model riverbeds

ABE CLARK, JULIA SALEVAN, Yale University, MARK SHATTUCK, City College of New York, NICHOLAS OUELLETTE, COREY O’HERN, Yale University — When fluid flows laterally over a granular bed, it exerts shear stress on the particles. The ratio of this stress to the gravitational stress is known as the Shields number, and bulk sediment transport is thought to occur once the Shields number has passed a critical threshold. However, the particle-scale mechanisms that control this transition are not well understood. Here, we perform molecular dynamics simulations of a model riverbed to understand the particle-scale origins of jamming and unjamming in these systems. The particles interact via purely repulsive harmonic forces and are coupled to the flow using a Stokes-like drag model. The interstitial fluid velocity is determined from the local packing density using a relation similar to Darcy’s law. Near the transition to sediment transport, we observe hysteresis and avalanches, and correlate their statistical properties to the packing geometry at the particle scale.

Funding: ARO W911NF-14-1-0005

10:24AM F49.00011 Erosion and flow of hydrophobic granular materials

BRIAN UTTER, THOMAS BENNS, BENJAMIN FOLTZ, JOSEPH MAHLER, James Madison University — We experimentally investigate submerged granular flows of hydrophobic and hydrophilic grains both in a rotating drum and under erosion by a surface water flow. While slurry and suspension flows are common in nature and industry, effects of surface chemistry on fluid behavior have received relatively little attention. In the rotating drum, we use varying concentrations of hydrophobic and hydrophilic grains of sand submerged in water rotated at a constant angular velocity. Sequential images of the resulting avalanches are taken and analyzed. High concentrations of hydrophobic grains result in an effectively cohesive interaction between the grains forming aggregates, with aggregate size and repose angle increasing with hydrophobic concentration. However, the formation and nature of the aggregates depends significantly on the presence of air in the system. We present results from a related experiment on erosion by a surface water flow designed to characterize the effects of heterogeneous granular surfaces on channelization and erosion.
This work is done in collaboration with Thomas Lessinnes and Derek Moulton.

In 1925, Timoshenko developed a general theory of growing elastic rods and birods. The theory leads to internal stresses, deformations, and possibly instabilities. A simple example of these structures is the bi-metallic strip first described by Timoshenko. The twist of the ribbon is increased in contrast with theoretical development, assuming infinitely thin, inextensible sheet. Using x-ray tomography, we are able to reconstruct the 3D shape of the ribbon. The observed singularities occur away from walls and boundaries, and the twisted ribbon configuration provides a unique opportunity to address the spontaneous formation of localized structures with great experimental flexibility.

We thank the financial support from the U.S. Department of Commerce, National Institute of Standards and Technology, the Office of the Director of Defense Research and Engineering (DDR&E) and the Air Force Office of Scientific Research.

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Work supported by NERSC and DOE.
12:39PM G44.00006 Coiling of elastic rods from a geometric perspective, MOHAMMAD JAWED, PIERRE-THOMAS BRUN, PEDRO REIS, Massachusetts Institute of Technology — We present results from a systematic numerical investigation of the pattern formation of coiling obtained when a slender elastic rod is deployed onto a moving substrate; a system known as the elastic sewing machine (ESM). The Discrete Elastic Rods method is employed to explore the parameter space, construct phase diagrams, identify their phase boundaries and characterize the morphology of the patterns. The nontrivial geometric nonlinearities are described in terms of the gravito-bending length and the deployment height. Our results are interpreted using a reduced geometric model for the evolution of the position of the contact point with the belt and the curvature of the rod in its neighborhood. This geometric model reproduces all of the coiling patterns of the ESM, which allows us to establish a universal link between our elastic problem and the analogous patterns obtained when depositing a viscous thread onto a moving surface; a well-known system referred to as the fluid mechanical sewing machine.

12:51PM G44.00007 The shape of strings to come: How topological defects twist, bend, and wrinkle filament bundles1, ISAAC BRUSS, GREGORY GRASON, Univ of Mass - Amherst — Topological defects are crucial to the thermodynamics and structure of condensed matter systems. For instance, when incorporated into crystalline membranes like graphene, 5- and 7-fold disclinations produce conical- and saddle-like geometries respectively. A recently discovered mapping between the inter-filament spacing within a deformed bundle and the metric properties of curved surfaces, suggests previously unexplored parallels between the two, specifically in regards to how 2D patterning promotes 3D shape transitions. This discovery is poised to describe the structure of a host of filamentous materials—both biological and microfabricated—that exhibit distinctive shapes and packings. Motivated by the filamentous analogs to the conical and saddles shapes found in thin membranes, we investigate for the first time the interplay between defects in the cross section of a bundle and its global structure, using a combination of continuum elasticity theory and numerical simulation of cohesive bundles with a fixed packing topology. Focusing primarily on the instability response to disclinations, we predict a host of new equilibria structures, some of which are without direct parallel to the analogous membrane, including orosional wrinkling, radial kinking, and helical winding.

1 Center for Hierarchical Manufacturing-CMMI 10-25020, NSF CAREER Award-DMR 09-55760, & UMass MRSEC

1:03PM G44.00008 Rotation of a Thin Elastic Rod Injected into a Cylindrical Constraint1, CONNOR MULCAHY, Massachusetts Institute of Technology, TIANXIANG SU, NATHAN WICKS, JAHR PABON, Schlumberger-Doll Research, PEDRO REIS, Massachusetts Institute of Technology — We report the results from an experimental investigation of the buckling of a thin elastic rod injected into a horizontal cylindrical constraint, with an emphasis on comparing the two cases of rotating, or not, the rod at the injection site. We are particularly interested on the total length of rod that can be injected into the pipe prior to the onset of helical buckling. This instability arises due to the frictional rod-constraint contact that eventually leads to the buildup of axial stress on the rod, above a critical value. We explore the dependence of the buckling conditions on the physical and control parameters of the system (e.g. material and geometric parameters, injection speed and rotation frequency) and rationalize the underlying physical mechanism through a reduced model.

1 Funding and support provided by Schlumberger-Doll Research.

1:15PM G44.00009 Stress localisation in annular sheets, GERT VAN DER HEIJDEN, EUGENE STAROSTIN, University College London — For very thin sheets stretching is much more costly in terms of energy than bending. The limiting behaviour of thin sheets is therefore governed by geometry only and thus applies to a wide range of materials at vastly different scales: it is equally valid for a microscopic graphene sheet and a macroscopic solar sail. We derive new geometrical-exact equations for the deformation of annular strips. We use a formulation in which the inextensibility constraint is used to reduce the problem to a suitably-chosen reference curve (here the circular centreline). The equations are therefore ODEs, which allow for a detailed bifurcation analysis. Closed conical solutions are found for centreline lengths \( L \) less than \( L_* = 2\pi \kappa_g \), where \( \kappa_g \) is the geodesic curvature of the strip. For such ‘short’ strips we find in addition a second branch of stable solutions easily reproduced in a paper strip. For ‘long’ strips \( (L > L_*) \) we find modes of undulating solutions. All non-conical solutions turn out to feature points of stress localisation on the edge of the annulus, the outer edge for short solutions and the inner edge of long solutions. Our theory may be used to investigate singularities of constrained or loaded sheets more general than conical ones.

1:27PM G44.00010 Large-deformation dynamics of an elastic filament at a fluid interface, SRINIVASA GOPALAKRISHNAN GANGA PRASATH, JOEL MARTHELOT, RAMA GOVINDARAJAN, TCIS, TIFR HYDERABAD AND DEPT. OF PHYSICS, UMass AMHERST, TCIS, TIFR HYDERABAD AND DEPT. OF PHYSICS, UMASS AMHERST COLLABORATION — We study the dynamics of a thin elastic filament at the interface of two fluids and observe the time evolution in its shape when released from an initial configuration with a large curvature. The unfolding of the filament is driven by a competition between bending energy and viscous dissipation. We experimentally study the overdamped regime of this system by varying fluid viscosity \((\eta)\), length \((L)\), diameter \((d)\) and elastic modulus \((E)\) of the filament with similar initial conditions and observe the kinematics of the filament straightening. The time-dependence for this process can be collapsed by scaling time by \(t_\mathrm{e} = \sqrt{\frac{3}{4\pi}}\). However, the characteristic time is very a small fraction of this time-scale. We perform numerical computations parallel to the experiments to get access to the dynamics of the filament to resolve this puzzle. An understanding of the time-dependence will enable the use of this technique to measure interfacial properties.

1:39PM G44.00011 Elasto-capillary windlass: from spider web to synthetic actuators1, HERVÉ ELETTRO, ARNAUD ANTKOWIAK, SÉBASTIEN NEUKIRCH, Institut D’Alembert, FRITZ VOLLRATH, Oxford Silk Group, INSTITUT D’ALEMBERT TEAM, OXFORD SILK GROUP TEAM — Spiders’ threads display a wide range of materials properties. The glue-covered araneid capture silk is unique among all silks because it is self tensing and remains taut even if compressed, allowing both thread and web to be in a constant state of tension. Here we demonstrate the filament to resolve this puzzle. An understanding of the time-dependence will enable the use of this technique to measure interfacial properties.

1 The present work was supported by ANR grant ANR-09-JCJC-0022-01, “La Ville de Paris - Programme Emergence,” Royal Society International Exchanges Scheme 2013/R1 grant 1E130506, and the PEPS PTI program from CNRS.

1:51PM G44.00012 Variability of Fiber Elastic Moduli in Composite Random Fiber Networks Makes the Network Softer, EHSAN BAN, CATALIN PICIU, Rensselaer Polytech Inst — Athermal fiber networks are assemblies of beams or trusses. They have been used to model mechanics of fibrous materials such as biopolymer gels and synthetic nonwovens. Elasticity of these networks has been studied in terms of various microstructural parameters such as the stiffness of their constituent fibers. In this work we investigate the elasticity of composite fiber networks made from fibers with moduli sampled from a distribution function. We use finite elements simulations to study networks made by 3D Voronoi and Delaunay tessellations. The resulting data collapse provides a posterior law describing that variability in fiber stiffness makes fiber networks softer. We also support the findings by analytical arguments. Finally, we apply these results to a network with curved fibers to explain the dependence of the network’s modulus on the variation of its structural parameters.
11:15AM G51.00001 Entangled active matter: from ants to living cells1. FRANCOISE BROCHARD-WYART, Institut Curie — We introduce the field of “Entangled Active Matter” where the building blocks are transiently bound. We will point out strong similarities between aggregates of ants and cells! We will use multicellular aggregates, a model system for tissues. We characterize the tissue mechanical properties using pipette aspiration technique. The aggregate exhibits a viscoelastic response. We observe aggregate reinforcement with pressure, which may result in pulsed contractions or “shivering.” We interpret this reinforcement as a mecano-sensitive active response of the acto-myosin cortex. We describe the spreading of aggregates on rigid and soft substrates, varying both intercellular and substrate adhesion. We find both partial and complete wetting, with a precursor film forming a cellular monolayer in a liquid or gas phase. We model the dynamics of spreading from a balance between active cellular driving forces and permeation of cells to enter into the film. Finally we study the motility of aggregates induced by chemical or rigidity gradients, or spontaneous: on soft substrate, the precursor film is unstable, leading to a symmetry breaking and a global motion of the aggregate. We describe the shapes of migrating aggregates, the flow and the force field responsible of the motion. We monitored the center of mass motion and we characterize the stick-slip motions.

1LABEX CelTisPhyBio, Institut Curie, France

11:51AM G51.00002 Free-standing thermalized graphene: a hard/soft hybrid1. DAVID NELSON, Department of Physics, Harvard University — Understanding deformations of macroscopic thin plates and shells has a long and rich history, culminating with the Föeppl-von Karman equations in 1904. These highly nonlinear equations are characterized by a dimensionless coupling constant (the “Föeppl-von Karman number”) that can easily reach $vK \sim 10^7$ in an ordinary sheet of writing paper. Since the late 1980’s, it has been clear that thermal fluctuations in macroscopically thin elastic membranes fundamentally alter the long wavelength physics, leading to a negative thermal expansion coefficient, and a strongly scale-dependent bending energy and Young’s modulus. Recent experiments from the McEuen group at Cornell that twist and bend individual atomically-thin free-standing graphene sheets (with $vK = 10^{13.1}$) call for a theory of the mechanical deformation of thermally excited membranes with large Föeppl-von Karman number. We present here results for the bending and pulling of thermalized graphene ribbons and tabs in the cantilever mode.

1Work done in collaboration with Andrei Kosmrlj.

12:27PM G51.00003 Liquids Gone With the Wind. DAVID QUÈRE, ESPCI, Paris — Self-propelling fluidic devices naturally result from some asymmetry of wettability, geometry or temperature. Here we consider the case of motions arising from the air around, forced by some trick to flow in an asymmetric way. We first consider vapor flows generated in a Leidenfrost situation, and made anisotropic by textures decorating the hot substrate. We discuss how the force and speed arising from these rectified vapor flows can be optimized. Then, we observe drops on a fiber placed in a symmetric wind. In a well-defined window of wind speed, the drop is found to self-propel along the fiber, which is analyzed. We also show that this effect makes drops moving in opposite direction bounce on each other, which generates fascinating 1-D dynamics.

In collaboration with Guillaume Dupeux, Philippe Bourrione, Dan Soto, Hélène de Maleprade, Pierre-Brice Bintein, Hadrien Bense and Christophe Clanet.

1:03PM G51.00004 Directed assembly in soft matter by energy stored in inclusions. KATHERINE STEBE, University of Pennsylvania — We have been exploiting fields that arise spontaneously when microparticles are placed in contact with deformable matter to direct assembly. In one context, we use capillary interactions that occur between anisotropic microparticles at fluid interfaces. The fluid interface deforms owing to the particle presence, creating an area field that bears the signature of the particle shape and wetting. We use curvature fields to direct particles to migrate, orient and assemble. In another context, we exploit elastic energies and defect fields that arise in liquid crystals. When a nematic liquid crystal is owing to the particle presence, creating an area field that bears the signature of the particle shape and wetting. We use curvature fields to direct assembly. In one context, we use capillary interactions that occur between anisotropic microparticles at fluid interfaces. The fluid interface deforms owing to the particle presence, creating an area field that bears the signature of the particle shape and wetting. We use curvature fields to direct particles to migrate, orient and assemble. In another context, we exploit elastic energies and defect fields that arise in liquid crystals. When a nematic liquid crystal is

1:39PM G51.00005 The Extreme Mechanics of Soft Structures1. PEDRO REIS, Massachusetts Institute of Technology — I will present a series of experimental investigations on the rich behavior of soft mechanical structures, which, similarly to soft materials, can undergo large deformations under a variety of loading conditions. Soft structures typically comprise slender elements that can readily undergo mechanical instabilities to achieve extreme flexibility and reversible reconfigurations. This field has come to be warmly known as Extreme Mechanics, where one of the fundamental challenges lies in rationalizing the geometric nonlinearities that arise in the post-buckling regime. I shall focus on problems involving thin elastic rods and shells, through examples ranging from the deployment of submarine cables onto the seabed, locomotion of uniflagellar bacteria, crystallography of curved wrinkling and its usage for active aerodynamic drag reduction. The main common feature underlying this series of studies is the prominence of geometry, and its interplay with mechanics, in dictating complex mechanical behavior that is relevant and applicable over a wide range of length scales. Moreover, our findings suggest that we rethink our relationship with mechanical instabilities which, rather than modes of failure, can be embraced as opportunities for functionality that are scalable, reversible, and robust.

1The author acknowledges financial support from the National Science Foundation, CMMI-1351449 (CAREER).

Tuesday, March 3, 2015 11:15AM - 2:15PM —
Session G51 GSOFT GSNP: Invited Session: Frontiers of Soft Matter II Grand Ballroom C1 - M.
Cristina Marchetti, Syracuse University

Tuesday, March 3, 2015 2:30PM - 5:18PM —
Session J42 GSNP: GSNP Student Speaker Award / Nonlinear Dynamics and Chaos 214B -
Adilson Motter, Northwestern University

2:30PM J42.00001 Phase Transitions on Random Lattices: How Random is Topological Disorder?2. HATEM BARGHATHI, THOMAS VOJTA, Missouri Univ of Sci & Tech — We study the effects of topological (connectivity) disorder on phase transitions. We identify a broad class of random lattices whose disorder fluctuations decay much faster with increasing length scale than those of generic random systems, yielding a wandering exponent of $\omega = (d - 1)/(2d)$ in $d$ dimensions. The stability of clean critical points is thus governed by the criterion $(d - 1)\nu > 2$ rather than the usual Harris criterion $d\nu > 2$, making topological disorder less relevant than generic randomness. The Imry-Ma criterion is also modified, allowing first-order transitions to survive in all dimensions $d > 1$. These results explain a host of puzzling violations of the original criteria for equilibrium and nonequilibrium phase transitions on random lattices. We discuss applications, and we illustrate our theory by computer simulations of random Voronoi and other lattices.

2This work was supported by the NSF under Grant Nos. DMR-1205803 and PHYS-1066293. We acknowledge the hospitality of the Aspen Center for Physics.
2:42PM J42.00002 Shear Jamming in Frictionless Particulate Media1, THIBAULT BERTRAN, COREY S. O’HERN, Yale University, R.P. BEHRINGER, Duke University, BULBUL CHAKRABORTY, Brandeis University, MARK D. SHATTUCK, City College of the City University of New York — We numerically study two-dimensional packings of frictionless bidisperse disks created using compresive and simple shearing protocols. To create jammed packings by compression, we start \(N\) particles from random positions and grow their diameters followed by relaxation of particle overlaps using energy minimization. These compressed packings exist over a range of packing fractions \(\phi\). As a result, during compression the system may reach a \(\phi\) above the minimum value before jamming. If this unjammed packing is then sheared by a strain \(\gamma\), it can jam. Using a combination of compression and shearing, we can define jamming protocols as trajectories in the \((\phi, \gamma)\) plane that yield jammed packings. In this plane, we can reach a particular point \((\phi_0, \gamma_0)\) in many ways. We will focus on two protocols: (1) shearing to \(\gamma_n\) at \(\phi = 0\) followed by compression to \(\phi_0\) at \(\gamma = \gamma_n\) and (2) compression to \(\phi_0\) at \(\gamma = 0\) followed by shearing to \(\gamma_n\) at \(\phi = \phi_0\). For protocol 1, we find that the probability of finding a jammed packing at \(\phi\) and \(\gamma\), \(P(\phi, \gamma) = Q(\phi)\) is independent of \(\gamma\). For protocol 2, we use a simple theory to deduce \(P(\phi, \gamma)\) from \(Q(\phi)\).

1W. M. Keck Foundation Science and Engineering Grant

2:54PM J42.00003 Three Dimensional Characterization of Quantum Vortex Dynamics in Superfluid Helium, DAVID MEICHELL, DANIEL LATHROP, University of Maryland — Vorticity is constrained to line-like topological defects in quantum superfluids, such as liquid Helium below the Lambda transition. We have invented a novel method to disperse fluorescent nanoparticles directly into the superfluid which become trapped on the vortex cores, providing optical tracers. Using a newly constructed multi-camera stereographic microscope, we present data dynamically characterizing quantum vortex trajectories. We find that vortex dynamics are diffusive on long-times even above the critical density for jamming. Our new model is a non-trivial extension of the two-dimensional spiral model

3:06PM J42.00004 Defect-Stabilized Phases in Extensile Active Nematics, GABRIEL REDNER, STEPHEN DECAMP, ZVONIMIR DOGIC, MICHAEL HAGAN, Brandeis University — Active nematics are liquid crystals which are driven out of equilibrium by energy-dissipating active stresses. The equilibrium nematic state is unstable in these materials, leading to beautiful and surprising behaviors including the spontaneous generation of topological defect pairs which stream through the system and later annihilate, yielding a complex, seemingly chaotic dynamical steady-state. In this talk, I will describe the emergence of order from this chaos in the form of previously unknown broken-symmetry phases in which the topological defects themselves undergo orientational ordering. We have identified these defect-ordered phases in two realizations of an active nematic: first, a suspension of extensile bundles of microtubules and molecular motor proteins, and second, a computational model of extending hard rods. I will describe the defect-stabilized phases that manifest in these systems, our current understanding of their origins, and discuss whether such phases may be a general feature of extensile active nematics.

3:18PM J42.00005 Jamming Percolation in Three Dimensions, EIAL TEOMY, Tel Aviv University, ANTINA GHOSH, Weizmann Institute, YAIR SHOKEF, Tel Aviv University — We introduce a three-dimensional kinetically-constrained model for jamming and glasses [1], and prove that the fraction of frozen particles is discontinuous at the directed-percolation critical density. In agreement with the accepted scenario for jamming- and glass-transitions, this is a mixed-order transition: the discontinuity is accompanied by emerging length- and time-scales. Because one-dimensional directed-percolation processes comprise the backbone of frozen particles, the unfrozen rattlers may use the third dimension to travel between their cages. Thus the dynamics are diffusive on long-times even above the critical density for jamming. Our new model is a non-trivial extension of the two-dimensional spiral model [2].


3:30PM J42.00006 Diffuse globally, compute locally: a cyclist approach to modeling long time robot locomotion, TINGNAN ZHANG, DANIEL GOLDMAN, PREDRAG CVITANOVIC, Georgia Institute of Technology — To advance autonomous robots we are interested to develop a statistical/dynamical description of diffusive self-propulsion on heterogeneous terrain. We consider a minimal model for such diffusion, the 2-dimensional Lorentz gas, which abstracts the motion of a light, point-like particle bouncing within a large number of heavy scatters (e.g. small robots in a boulder field). We present a precise computation (based on exact periodic orbit theory formula for the diffusion constant) for a periodic triangular Lorentz gas with finite horizon. We formulate a new approach to tiling the plane in terms of three elementary tiling generators which, for the first time, enables use of periodic orbits computed in the fundamental domain (that is, \(\frac{1}{2}\) of the hexagonal elementary cell whose translations tile the entire plane). Compared with previous literature, our fundamental domain value of the diffusion constant converges quickly for inter-disk separation/disk radius \(>0.2\), with the cycle expansion truncated to only a few hundred periodic orbits of up to 5 billion wall bounces. For small inter-disk separations, with periodic orbits up to 6 bounces, our diffusion constants are close (\(<10\%\)) to direct numerical simulation estimates and the recent literature probabilistic estimates.

3:42PM J42.00007 Fractal Geometry of Undriven Dissipative Systems, XIAOWEN CHEN, TAKASHI NISHIKAWA, ADILSON E. MOTTER, Department of Physics and Astronomy, Northwestern University — Traditional studies of chaos in conservative or driven dissipative systems have established a correspondence between sensitive dependence on initial conditions and fractal basin boundaries. Here, we present data dynamically characterizing fractal basin trajectories. We find that fractal basins are systematically “compressed” into a few macroscopic degrees of freedom, effectively building a bridge between the microscopic and the macroscopic descriptions.

4:06PM J42.00009 Model reduction by manifold boundaries, MARK TRANSTRUM, Brigham Young University — Mathematical models of physical systems can be interpreted as manifolds of predictions embedded in the space of data. For models of complex systems with many parameters, the corresponding model manifold is very high-dimensional but often very thin. This “low effective dimensionality” has been described as a hyperribbon and is characteristic of systems exhibiting simple, emergent behavior. I discuss a new model reduction method, the manifold boundary approximation method, which constructs a series of models by iteratively approximating the high-dimensional, thin manifold by its boundary. This model reduction method unifies many different model reduction techniques, such as renormalization group and continuum limits, while greatly expanding the domain of tractable models. I demonstrate with a model of a complex signaling network from systems biology. The method produces a series of approximations which reveal how microscopic parameters are systematically “compressed” into a few macroscopic degrees of freedom, effectively building a bridge between the microscopic and the macroscopic descriptions.
the organizing principle(s) which govern jamming by shear, and systematic reorganization under cyclic driving.

1

replacing energy

phase transition.

stabilities have been examined for the three-particle system. The behavior of the system in the thermodynamic limit has been simulated using large versions

and the thermodynamics of a single-component one-dimensional plasma with periodic boundary conditions. For a system of the plasma with three particles, we

plot the Poincare maps and calculate the largest Lyapunov exponents. The results indicate that the three-particle system exhibits interesting dynamics with the

and the phenomenon of self-reanimating chaos. Additionally, we investigate the long-term behavior of the system as a function of both initial conditions and parameter values. We find novel bifurcation phenomena not seen in the sinusoidal model. Our investigations reveal that, although the piecewise linear bouncer is a simplified version of the sinusoidal model, it captures essential features of the latter and also exhibits behavior unique to the discontinuous dynamics.

1 We would like to acknowledge the support of the REU program at TCU, NSF grant PHY-1358770.

4:20PM J42.00012 Nonlinear Dynamics and Thermodynamics of a One-Dimensional Plasma in Simulation, PANKAJ KUMAR, BRUCE MILLER, Texas Christian University, JEAN-LOUIS ROUET, Université d'Orléans — We report on the results of a simulation study of the nonlinear dynamics and the thermodynamics of a single-component one-dimensional plasma with periodic boundary conditions. For a system of the plasma with three particles, we plot the Poincare maps and calculate the largest Lyapunov exponents. The results indicate that the three-particle system exhibits interesting dynamics with the phase-space containing periodic, quasiperiodic, as well as chaotic regions for different initial conditions. Special periodic orbits have been identified and their stabilities have been examined for the three-particle system. The behavior of the system in the thermodynamic limit has been simulated using large versions of the system and the dependences of the pressure, the coupling strength and the largest Lyapunov exponent on the average per-particle kinetic energy are presented. The results of the thermodynamic-limit simulations indicate that the net pressure is equal to the kinetic pressure for all temperatures and there is no phase transition.

4:54PM J42.00013 Evolution of a One-dimensional, Two Component, Universe, YUI SHIOZAWA, BRUCE MILLER, Texas Christian University, JEAN-LOUIS ROUET, Université d'Orléans — While the universe we observe today exhibits local filament-like structures, with stellar clusters and large voids between them, the primordial universe is believed to have been nearly homogeneous with slight variations in matter density. To understand how the observed hierarchical structure was formed, researchers have developed a one-dimensional analogue of the universe that can simulate the evolution of a large number of matter particles. Investigations to date demonstrate that this model reveals structure formation that shares essential features with the three-dimensional observations. In the present work, we have expanded on this concept to include two species of matter, specifically dark matter and luminous matter. In our simulation, luminous matter is treated in a way that loses energy in interaction with itself. The results of the simulations clearly show the formation of a Cantor set like multifractal pattern over time in configuration space as well as in phase space. In contrast with most earlier studies, mass-oriented methods for computing the multifractal dimensions were performed on various subsists of the matter distribution in order to understand the bottom-up structure formation.

5:06PM J42.00014 Cosmology in One Dimension: Fractal Dimensions from Mass Oriented Partitions, BRUCE MILLER, Texas Christian University, JEAN-LOUIS ROUET, Université d'Orléans, YUI SHIOZAWA, Texas Christian University — The distribution of visible matter in the universe has its origin in the weak fluctuations of density that existed at the epoch of recombination. The hierarchical distribution of the present universe, with its galaxies, clusters and super-clusters of galaxies indicates the absence of a natural length scale. Numerical simulations of a one-dimensional system permit us to precisely follow the evolution starting with an initial perturbation in the Hubble flow. The limitation to one dimension removes the necessity to make approximations in calculating the gravitational field and the system dynamics. It is then possible to accurately follow the trajectories of particles for a long time. The simulations show the emergence of a self-similar hierarchical structure in both the phase space and the configuration space and invite the implementation of a multifractal analysis. Here we apply four different methods for computing generalized fractal dimensions $D_q$ of the distribution of particles in configuration space. We first employ the conventional methods based on partitions of equal size and then less familiar methods based on partitions of equal mass. We show that the latter are superior for computing generalized dimensions for indices $q < -1$ which characterize regions of low density.

Tuesday, March 3, 2015 2:30PM - 4:54PM — Session J44 GSNP: Invited Session: Self-assembly in the Macro-World 214D - Corey O'Hern, Yale University

2:30PM J44.00001 Self-assembly and the Formation of Structure in Granular Materials, ROBERT BEHRINGER, Duke University — Particle systems self-assemble in ways that are sensitive to their environments. Proteins fold, polymers crosslink, and molecular systems form crystals. Granular materials, unlike proteins, polymers or molecules, are not sensitive to temperature, and will only form new structures when they are driven. This raises the question of how a granular state depends on the preparation protocol, and an even more basic question of what is needed to specify a granular state. I will focus on granular systems near jamming, where key state variables include the density and stresses. Systems of frictionless grains follow the Liu-Nagel scenario of jamming, with a lowest packing fraction, $\phi_J$, such that any system with $\phi < \phi_J$ is unjammed, and all isotopic states (shear stress $\tau = 0$) are jammed for $\phi \geq \phi_J$. For frictional grains the picture changes. For a given $\phi$ in the range $\phi_S < \phi < \phi_J$, it is possible to have stress-free (unjammed) states, highly anisotropic fragile states, and robustly jammed states. The fragile and strongly jammed states form spontaneously in response to shear. By inference, $\phi$ is not a state variable, but recent experiments indicate that the non-rattler fraction, $f_{NR}$, is. In $\phi_S \leq \phi < \phi_J$, the system response is inherently non-linear; under cyclic shear, the system self-organizes to new steady states via a process that resembles thermal activation, with shear stress replacing energy. The activation is provided by shear strain. We observe similar relaxation under cyclic compression. An important question is, what is (are) the organizing principle(s) which govern jamming by shear, and systematic reorganization under cyclic driving. 1Liu, A. & S. Nagel, Nature 396, 21 (1998). 2D. Bi et al., Nature 480, 355 (2011). 3 J. Ren et al. Phys. Rev. Lett. 110, 018302 (2013)

3 NSF grants DMR1206351 and DMS1248071, NASA grant NNX10AU10G, and ARO grant W911NF-1-11-0110
3:06PM J44.00002 Emergent Behavior in the Macro World: Rigidity of Granular Solids
BULBUL CHAKRABORTY, Brandeis Univ — Diversity in the natural world emerges from the collective behavior of large numbers of interacting objects. The origin of collectively organized structures over the vast range of length scales from the subatomic to colloidal is the competition between energy and entropy. Thermal motion provides the mechanism for organization by allowing particles to explore the space of configurations. This well-established paradigm of emergent behavior breaks down for collections of macroscopic objects ranging from grains of sand to asteroids. In this macro-world of particulate systems, thermal motion is absent, and mechanical forces are all important. We lack understanding of the basic, unifying principles that underlie the emergence of order in this world. In this talk, I will explore the origin of rigidity of granular solids, and present a new paradigm for emergence of order in these athermal systems.

3:42PM J44.00003 Designing Jammed Materials from the Particle Up
MARC MISKIN, Cornell University — Identifying which microscopic features produce a desired macroscopic behavior is a problem at the forefront of materials science. This task is materials design, and within it, new challenges have emerged from tailoring packings of particles jammed into a rigid state. For these materials, particle shape is a key parameter by which the response of a packing can be tuned. Yet designing via shape faces two unique complications: first there is no general theory that calculates the response of an aggregate given a particle shape, and second, there is no straightforward way to explore the space of all particle geometries. This talk summarizes recent results that address these challenges to design jammed materials from the particle up. It shows how simulations, experiments, and state-of-the-art optimization engines come together to form a complete system that identifies extreme materials. As examples, it will show how this system can create particle shapes that form the stiffest, softest, densest, loosest, most dissipative and strain-stiffening aggregates. Finally, it will discuss how these results relate to the general task of materials design and the exciting possibilities associated with optimizing, tuning and rationally constructing new breeds of jammed materials.

4:18PM J44.00004 Self-assembly of granular crystals
MARK SHATTUCK, Benjamin Levich Institute, City College of New York — Acoustic meta-materials are engineered materials with the ability to control, direct, and manipulate sound waves. Since the 1990s, several groups have developed acoustic meta-materials with novel capabilities including negative index materials for acoustic super-lenses, phononic crystals with acoustic band gaps for wave guides and mirrors, and acoustic cloaking device. Most previous work on acoustic meta-materials has focused on continuum solids and fluids. In contrast, we report on coordinated computational and experimental studies to use macro-self-assembly of granular materials to produce acoustic meta-materials. The advantages of granular acoustic materials are three-fold: 1) Microscopic control: The discrete nature of granular media allows us to optimize acoustic properties on both the grain and network scales. 2) Tunability: The speed of sound in granular media depends strongly on pressure due to non-linear contact interactions and contact breaking. 3) Direct visualization: The macro-scale size of the grains enables visualization of the structure and stress propagation within granular assemblies. We report simulations and experiments of vibrated particles that form a variety of self-assembled ordered structures in two- and three-dimensions. In the simplest case of mono-disperse spheres, using a combination of pressure and vibration we produce crystals with long-range order on the scale of 100's of particles. Using special particle shapes that form "lock and key" structures we are able to make binary crystals with prescribed stoichiometries.
We discuss the mechanical properties of these structures and methods to create more complicated structures.

Tuesday, March 3, 2015 2:30PM - 5:30PM — Session J45 GSNP DPOLY: Focus Session: Extreme Mechanics 216AB - Joel Marthelot, Massachusetts Institute of Technology

2:30PM J45.00001 Graphene Statistical Mechanics
MARK BOWICK, Syracuse University, ANDREJ KOSMRLJ, DAVID NELSON, Harvard University, RASTKO SKNEPNEK, University of Dundee — Graphene provides an ideal system to test the statistical mechanics of thermally fluctuating elastic membranes. The high Young’s modulus of graphene means that thermal fluctuations over even small length scales significantly stiffen the renormalized bending rigidity. We study the effect of thermal fluctuations on graphene ribbons of width W and length L, pinned at one end, via coarse-grained Molecular Dynamics simulations and compare with analytic predictions of the scaling of width-averaged root-mean-squared height fluctuations as a function of distance along the ribbon. Scaling collapse as a function of W and L also allows us to extract the scaling exponent eta governing the long-wavelength stiffening of the bending rigidity. A full understanding of the geometry-dependent mechanical properties of graphene, including arrays of cuts, may allow the design of a variety of modular elements with desired mechanical properties starting from pure graphene alone.

1Supported by NSF grant DMR-1435794

2:42PM J45.00002 Fanning the Optimal Breeze with an Abanico
GRACE GOON, JOEL MARTHELOT, PEDRO REIS, Massachusetts Institute of Technology — Flexible hand-held fans, or abanicos, are universally employed as cooling devices that are both portable and sustainable. Their to and fro axial motion about one’s hand generates an airflow that increases the evaporation rate near the skin and refreshes. We study this problem in the context of fluid-structure interaction, through precision model experiments. We first characterize the elastic properties of a number of commercially available fans and evaluate their aerodynamic performance in a custom built apparatus. The air velocity profile that results from the flapping motion of the fan is characterized for different driving conditions. We then fabricate our own analogue model fans that comprise a thin elastic plate, shaped as a circular section, with an underlying substructure of radial slats. A systematic variation of the geometric and elastic parameters, along with an exploration of the parameter space of the periodic driving motion (amplitude and frequency), allows us to establish optimal design and operational conditions for maximal output of the generated airflow, while minimizing the input power.

2:54PM J45.00003 Theoretical and experimental analysis of mylar balloons
ANTONIO ROMAGUERA, Universidade Federal Rural de Pernambuco, VINCENT DÉMЕRY, BENNY DAVIDOVITCH, UMass - Amherst — In the present study, we present a theoretical and experimental study of the problem known as the mylar balloon shape. The problem consists of inflating a balloon made of two circular discs of an unstretchable material sewed at the edge. A solution for this problem was given by W. H. Paulsen in 1994 for constrain free. In our analyzes, we fixed the height of the balloon and measure the inflated diameter. As a result, we were able to map the constrained shape in terms of the original mylar balloon’s shape. The basic assumption of this problem is that the gravitational, stretching and bending energies are negligible compared with the mechanical energy \( -pV \). Controlling the pressure and the height of the balloon, we are able to find the condition where these assumptions fail, specially in the limit \( h \to 0 \) for fixed \( p \). A remarkable feature of this problem is the presence of wrinkles across the equator of the balloon. A precise description for that region must include the large deformation from the flat disc initial condition. We will also present some experimental data on the wrinkle’s length and its connection with the pressure and height of the balloon.
3:06PM J45.00004 Voltage Induced Buckling Instability, a Means for Advanced Functionality within Soft Materials, BEHROUZ TAVAKOL, SARAH E. BEAUCHAMP, ASCHVIN CHAN, Virginia Tech, DOUGLAS P. HOLMES, Boston University — Instabilities within structures composed of soft materials may provide advanced functionality. We use the buckling of thin dielectric plates for pumping fluids and controlling the flow rate within microchannels. When exposed to an electric field, a confined dielectric plate buckles out of the plane, and this buckling can stop or enhance the flow rate of surrounding media. Compliant or greasy electrodes have conventionally been used to aid in voltage application to both sides of the dielectric film. Here we introduce fluid electrodes, which make this mechanism embeddable into micro devices, enable the buckling at lower voltages, and significantly enhance the rate of deformation. We show that this mechanism can function as a microvalve to control the flow rate, or as a micropump to enhance the flow rate. We also examine buckled shapes of the dielectric film using a scaled-up version with fluid electrodes. These reversible, voltage-induced buckling instabilities can potentially be used in a variety of different applications to control or enhance fluid flow in micro devices.

3:18PM J45.00005 Discontinuous Buckling , LUUK LUBBERS, CORENTIN COULIAIS, Universite Leiden, JOHANNES OVERVELDE, KATIA BERTOLDI, Harvard University, MARTIN VAN HECKE, Universiteit Leiden — Buckling of beams under uniaxial loading is perhaps the most basic example of an elastic instability. In this talk we show that sufficiently wide beams exhibit discontinuous buckling, an unstable form of buckling where the post-buckling stiffness is negative. We develop a 1D model that matches our experimental and numerical data and identify nonlinearity as the main cause for negative stiffness. We then utilize this non-linearity to create metamaterials that allow us to rationally design the (negative) post-buckling stiffness of metamaterials, independently of beam thickness, thereby making it possible to violate Euler’s limit for slender beam buckling.

3:30PM J45.00006 Bulk Elastic Fingering in Soft Materials, BAUDOUIN SAINTYVES, Harvard University, JOHN BIGGINS, Cambridge University, ZHIYAN WEI, Stanford University, SERGE MORA, Montpellier 2 University, ELIS-ABETH BOUCHAUD, ESPCI-PARISTECH, HARVARD UNIVERSITY TEAM, ESPCI-PARISTECH COLLABORATION, CAMBRIDGE UNIVERSITY COLLABORATION, MONTPELLIER 2 UNIVERSITY COLLABORATION — Systematic experiments have been performed in purely elastic polycrystalline gels in Hele-Shaw cells. We have shown that a bulk fingering instability arises in the highly deformable confined elastomers. A systematic study shows that surface tension is not relevant. This instability is sub-critical, with a clear hysteretic behavior. Our experimental observations have been compared very favorably to theoretical and finite element simulations results. In particular, the instability wavelength and the critical front advance have been shown to be proportional to the distance between the two glass plates constituting the cell. A very important feature is that elasticity doesn’t influence this lengthscale, making this instability very generic. We will also show some new results about an elastic counterpart experiment of the famous Saffman-Taylor experiment, where we push a soft gel in a stiff one.

3:42PM J45.00007 Mechanical properties of 3D printed warped membranes, ANDREJ KOSMRLJ, KECHAO XIAO, JAMES C. WEAVER, JOOST J. VLASSAK, DAVID R. NELSON, Harvard University — We explore how a frozen background metric affects the mechanical properties of solid planar membranes. Our focus is a special class of “warped membranes” with a preferred random height profile characterized by random Gaussian variables $h(q)$ in Fourier space with zero mean and variance $\langle |h(q)|^2 \rangle \sim q^{-m}$. It has been shown theoretically that in the linear response regime, this quenched random disorder increases the effective bending rigidity, while the Young’s and shear moduli are reduced. Compared to flat plates of the same thickness $t$, the bending rigidity of warped membranes is increased by a factor $\sim h_0/t$, where $h_0 = \sqrt{\langle |h(x)|^2 \rangle}$ describes the frozen height fluctuations. Interestingly, $h_0$ is system size dependent for warped membranes characterized with $m > 2$. We present experimental tests of these predictions, using warped membranes prepared via high resolution 3D printing.

3:54PM J45.00008 Localization in an Idealized Heterogeneous Elastic Sheet, BEKELE GURMESSA, ANDREW B. CROLL, North Dakota State Univ — Localized deformation is ubiquitous in many natural and engineering materials. Often times such deformations are associated to non-homogeneous strain fields in the materials. In this work we demonstrate the response of idealized non-homogeneous elastic sheets to uniaxial compression. The idealized/patterned surface layers are created by selective ultraviolet/ozone (UVO) treatment of the top surface of polydimethylsiloxane (PDMS) using TEM grid mask. By controlling the exposure time of the UVO, samples ranging from continuous thin films to sets of isolated small plates were created. We show how local strains vary with location in a patterned sample, leading to a complex localization process Even at low strains. We also see that continuous regions form isotropic undulations upon compression which persist to high strains, well beyond where localization is observed in the patterned regions. Despite the complexity, the localized deformation profile can be adequately described with a simple elastic model when appropriate local boundary conditions are considered.

4:06PM J45.00009 Primary and secondary bifurcations in compressed elastomeric bilayers with small modulus contrast, ANESIA AUGUSTE, University of Massachusetts Amherst, LIHUA JIN, ZHIGANG SUO, Harvard University, RYAN C. HAYWARD, University of Massachusetts Amherst — Elastic materials undergo various kinds of elastic instabilities when subjected to compression. The primary bifurcation behavior for a stiff thin film on a thick soft substrate is wrinkling, whereas for a homogeneous material it is creasing. While ideal bilayered systems with large contrasts in modulus and thickness are well understood, many system in nature and engineering contexts are far from this simple case. We have developed an experimental system to systematically vary the modulus contrast, complemented by finite element simulations, to study the primary and secondary bifurcations in compressed bilayers. We find that below a ratio of film to substrate elastic modulus of approximately 2, the primary bifurcation is creasing. For slightly larger contrasts, the primary bifurcation is wrinkling but there are two distinct types of secondary bifurcations: (1) wrinkles that transition into creases without period-doubling; and (2) wrinkles to creases preceded by period doubling. Understanding surface instabilities in such non-ideal bilayer systems provides important insights on the behavior of biological tissues and other systems with a small modulus contrast.

4:18PM J45.00010 The Structural Change of Buckling Depending on the Directional Mechanical Heterogeneity of Top Thin Films, DOKYEONG KWON, Seoul Natl Univ, HYOSEON SUH, University of Chicago, DOMIN KIM, KOOKHEON CHAR, Seoul Natl Univ — Buckling of thin films on elastomeric substrates such as polydimethylsiloxane (PDMS) is the well-known phenomenon in buckling instability originating from the modulus mismatch between a substrate and a thin film placed on the top. Recently, many studies on the microstructure created by the buckling with flat top films have been reported and physics behind them has almost been well received. However, only a few work has been done for the buckling structure with micropatterned top films and buckling mechanics for patterned top film-PDMS bilayers has not yet been studied in detail. Here, we present the buckling of mechanically heterogeneous, patterned top films placed on top of elastomeric PDMS substrates. Mechanically heterogeneous top films were prepared by polystyrene (PS) films with topographic patterns. Buckling instability was induced by applying mechanical stresses to the PS-PDMS bilayer. Resulting buckling structure showed the structural change depending on the alignment of the top films with respect to the buckling direction. The structural change was analyzed with finite element method calculation, giving insights on the buckling mechanics of top film with complicated patterns placed on PDMS substrates.
4:30PM J45.00011 High Aspect Ratio Wrinkles, YU-CHENG CHEN, ALFRED CROSBY, University of Massachusetts Amherst — Buckling-induced surface undulations are widely found in living creatures, for instance, gut villi and the surface of flower petal cells. These undulations provide unique functionalities with their extremely high aspect ratios. For the synthetic systems, sinusoidal wrinkles that are induced by buckling a thin film attached on a soft substrate have been proposed to many applications. However, the impact of the synthetic wrinkles have been restricted by limited aspect ratios, ranging from 0 to 0.35. Within this range, wrinkle aspect ratio is known to increase with increasing compressive strain until a critical strain is reached at which point wrinkles transition localization, such as folds or period doublings. Inspired by the living creatures, we propose that wrinkles can be stabilized in high aspect ratio by manipulating the strain energy in the substrate. We experimentally demonstrate this idea by forming a secondary crosslinking network in the wrinkled surface and successfully achieve aspect ratio as large as 0.8. This work not only provides insights for the mechanism of high aspect ratio structures seen in living creatures, but also demonstrates significant promise for future wrinkle-based applications.

4:42PM J45.00012 Competition between adhesion and inertia during stick-slip peeling of Pressure Sensitive Adhesives, M.-J. DALBE, Laboratoire de Physique de l’ENS de Lyon, CNRS, Université de Lyon, France, R. VILLEY, Laboratoire FAST, CNRS, Université Paris-Sud, Orsay, France, M. CICCOTTI, Laboratoire PPM/STIMM, CNRS, ESPCI ParisTech, Paris, France, P.-P. CORTET, FAST, S. SANTUCCI, Laboratoire de Physique de l’ENS de Lyon, L. VANEL, Institut Lumière Matière, CNRS, Université de Lyon, France — We consider the classical problem of the instable stick-slip dynamics often observed when peeling a pressure sensitive adhesive, quantifying for the first time experimentally the influence of the peeling angle. This instability is known to be the consequence of a decreasing fracture energy of the adhesive-substrate joint over a certain range of driving velocity: we focus here on the important case where the instability develops at large driving velocity. We show that the shape of the peeling front velocity fluctuations progressively changes from typical stick-slip relaxation oscillations to nearly sinusoidal oscillations as the peeling angle and/or the driving velocity is increased. This transition is accompanied with a change in the dependencies of the limit cycles’ period on the control parameters. We show that it results from the competition, in the dynamical equation, between the standard fracture energy and a term —considered here for the first time— associated to the freestanding tape elasticity and inertia. We manage to predict quantitatively the transition of the instability amplitude and period from the classical Barquins-Maugis quasistatic regime to a purely inertial regime in which the adhesion energy is no more at play in setting the instability limit cycles.

4:54PM J45.00013 Influence of large strain rheology on the peeling performances of Pressure Sensitive Adhesives, RICHARD VILLEY, MATTEO CICCOTTI, COSTANTINO CRETON, Laboratoire STIMM, CNRS, ESPCI ParisTech, Université Pierre et Marie Curie, PSL Research University, Paris, France, PIERRE-PHILIPPE CORTET, Laboratoire FAST, CNRS, Université Paris-Sud, Orsay, France, DAVID J. YARUSSO, 3M Company, 3M Center, 230-1D-15, St. Paul, MN, 55144-1000, USA — The dependence of adhesion energy of Pressure Sensitive Adhesives (PSA) on peeling velocity reduces to a master curve using a time-temperature superposition principle, usually verified by the linear rheology of polymers. This result has guided models predicting peeling energy of PSA to consider the small strain rheology of the glue only, despite it can experience very large strains before debonding. The argument of the time-temperature superposition principle can actually also be applied to large strains and is thus not a stringent one. To clarify the role of large strain rheology during the peeling of PSA, we present experiments on commercial and custom-made tapes supplied by 3M Company. Small and large strain rheology differences are obtained by changing the glass transition temperature, the cross-linking density and the density of entanglements, yet remaining close to commercial PSA. The rheology influence is decoupled from geometrical effects, by examining the nontrivial dependence of the adhesion energy on the peeling angle. Finally, adhesion energy measurements and visualizations of the process zone, over a large range of peeling velocities, are discussed, in the perspective of building a model for the adhesion considering the complete rheology of the glue.

5:06PM J45.00014 What can cracked polymer do, KEVIN JIAO, CHUANGHONG ZHOU, PUNIT KOHLI, Department of Chemistry and Biochemistry, Southern Illinois University Carbondale, ANISH POUDEL, TSUCHIN CHU, College of Engineering, Southern Illinois University Carbondale — Buckling, delamination, and cracking are very well known phenomenon observed in most thin films. They were theoretically explained by the existence of mechanical instability due to the residue stress generated when a thin film is deposited on substrates or undergoing environmental stimulus. Buckled structures at micro- or nano-scale have been of great interests and have been used extensively in many applications including particles self-assembling, surface wettability modification, and micro-electronic device fabrication. However, peeling of a layer from a substrate due to delamination or fractures on a thin film due to cracking is mostly taken as an undesirable result. Therefore, strategies are inspired for preventing or removing these often undesired structures. We found that after being heated above its decomposition temperature and then cooled to room temperature, a PDMS thin film showed micro-fibers of 100µm width and up to 1.5 cm in length. By studying the formation mechanism, control of the dimensions and of the growth pattern on a substrate for PDMS micro-fibers were realized. Giving credit to their high flexibility and optical transparency, a PDMS micro-fiber were utilized in high resolution near field imaging achieved by attaching a micro-lens on the fiber. Interestingly, a surface covered by PDMS micro-fibers will turn from superhydrophobic into superhydrophilic by further heating providing potential applications in surface wettability modification. In future, we will investigate and simulate the growth of PDMS micro-fiber and look for more possible applications.

5:18PM J45.00015 Formation of $^3$He droplets in dilute $^3$He-$^4$He solid solutions, CHAO HUAN, University of Florida, Gainesville, USA, DON CANDELA, University of Massachusetts, Amherst, USA, SUNG KIM, LIANG YIN, JIANG-SHENG XIA, NEIL SULLIVAN, University of Florida, Gainesville, USA — We review the different stages of the formation of $^3$He droplets in dilute solid $^3$He-$^4$He solutions. The studies are interesting because the phase separation in isotopic helium mixtures is a first-order transition with a conserved order parameter. The rate of growth of the droplets as observed in NMR studies [1] is compared with the rates expected for homogeneous nucleation followed by a period of coarsening known as Ostwald ripening. [1] C. Huan et al., J. Low Temp. Phys. 162,167 (2011).

Tuesday, March 3, 2015 2:30PM - 5:30PM –
Session J51 GSNP GSOFT: Invited Session: Irwin Oppenheim Memorial Session: Non-Equilibrium Statistical Mechanics of Liquids, Glasses and Biomolecules
Grand Ballroom C1 - Eli Ben-Naim, Los Alamos National Laboratory
2:30PM J51.00001 Dynamical coarse grained models with realistic time dependence . HANS ANDERSEN, Department of Chemistry, Stanford University — Coarse grained (CG) models of molecular systems, with fewer mechanical degrees of freedom than an all-atom model, are used extensively in chemical physics. It is generally accepted that a coarse grained model that accurately describes equilibrium structural properties (as a result of having a well constructed CG potential energy function) does not necessarily exhibit appropriate dynamical behavior when simulated using conservative Hamiltonian dynamics for the CG degrees of freedom on the CG potential energy surface. Attempts to develop accurate CG dynamic models usually focus on replacing Hamiltonian motion by stochastic but Markovian dynamics on that surface, such as Langevin or Brownian dynamics. However, depending on the nature of the system and the extent of the coarse graining, a Markovian dynamics for the CG degrees of freedom may not be appropriate. We consider the problem of constructing dynamic CG models within the context of the Multi-Scale Coarse Graining (MS-CG) method of Voth and coworkers. We propose a method of converting an MS-CG model into a dynamic CG model by adding degrees of freedom to it in the form of a small number of fictitious particles that interact with the CG degrees of freedom in simple ways and that are subject to Langevin forces. The dynamic models are members of a class of nonlinear systems interacting with special heat baths that was studied by Zwanzig [R. Zwanzig, J. Stat. Phys. 9, 215 (1973)]. The dynamic models generate a non-Markovian dynamics for the CG degrees of freedom, but they can be easily simulated using standard molecular dynamics simulation programs. We present tests of this method on a series of simple examples that demonstrate that the method provides realistic dynamical CG models that have non-Markovian or close to Markovian behavior that is consistent with the actual dynamical behavior of the all-atom system used to construct the CG model. The dynamic CG models have computational requirements that are similar to those of the corresponding MS-CG model and are good candidates for CG modeling of very large systems.

3:06PM J51.00002 Competing dynamics of vitrification and crystal coarsening . DAVID CHANDLER, University of California, Berkeley — Materials undergoing glass transitions are often materials that can also crystallize. The qualities of the solid that forms depend upon the system’s dynamics and experimentalist’s protocols. This lecture describes some of the associated phenomena, including competition between crystal nucleation and structural relaxation, transient domains and dynamic heterogeneity, grain boundaries and polycrystallinity. A stochastic model from which all of these phenomena emerge will be presented.

3:42PM J51.00003 Brownian motion, old and new, and Irwin’s role in my academic life . KATJA LINDENBERG, Univ of California - San Diego — Irwin Oppenheim’s early work on Langevin equations, master equations, and Brownian motion was one of the earliest and strongest reasons for my change of direction from my PhD work in condensed matter theory to my later and lifelong interest in Brownian motion and, more broadly, statistical mechanics. I will talk about some of my most recent work on subdiffusion, a form of anomalous diffusion that describes random motions in crowded or disordered media where motions are hindered by the medium. On a personal note, I knew Irwin for decades, from the time before he had a family (he was a sworn bachelor...until he met his wife) until shortly before his death. For many years, first alone and then with family, Irwin would spend some portion of the cold Boston winter in warm La Jolla, and we would always get together during these visits. For a period of a number of years we decided to take advantage of these visits to write the definitive text in traditional Thermodynamics. We did not make it past about 2/3 of the project, but it was a great learning experience for me while it lasted. Irwin’s knowledge and understanding of the subject were breathtaking.

4:18PM J51.00004 Ion Atmosphere Near Nucleic Acids1 . UDAYAN MOHANTY, Department of Chemistry, Boston College — We will discuss allatom structure based model that explicitly includes ionic effects, i.e., electrostatic interactions with explicit magnesium ions and implicit KCl that allow us to carry out explicit solvent molecular dynamics simulations of adenine riboswitch and SAMI riboswitch. Our predictions for the excess ions around the riboswitch, and the magnesiumRNA interaction free energy will be compared with experimental data. We will provide upper and lower bounds for preferential interaction coefficient, a statistical mechanical quantity that is a measure of excess ion atmosphere around a polyelectrolyte. We will discuss the role of surface charge density of mobile ions from added salt in determining the counterion release entropy associated with chain collapse. Finally, the Poisson’s ratio of oligomeric DNA will be determined. (Work done in collaboration with R. Hayes, J. Noel, P. Whiting, S. Hennelly, J. Onuchic, and K. Sanbonmatsu.)

4:54PM J51.00005 The Typical Lengthscale Characterizing the Glass Transition at Lower Temperatures . ITAMAR PROCACCIA, The Weizmann Institute of Science — The existence of a static length scale that grows in accordance with the dramatic slowing down observed at the glass transition is a subject of intense interest. A recent publication compared two proposals for this length scale, one based on the point-to-set correlation technique and the other on the scale where the lowest eigenvalue of the Hessian matrix becomes sensitive to disorder. The conclusion was that both approaches lead to the same length scale, but the former is easier to measure at higher temperatures and the latter at lower temperatures. But even after using both methods together, the range of increase in the observed length scales was limited by the relaxation times reachable by standard molecular dynamics techniques (i.e. about 4-5 orders of magnitude). In this paper we therefore attempt to explore the typical scale at even lower temperatures, testing for this purpose two approaches, one based on the idea of vapor deposition and the other on a swap Monte Carlo technique. We conclude that the first approach does not help in getting to lower temperatures, but the second one does so quite effectively. We can reach a typical lengthscale that grows in accordance with at least 18 orders of magnitude increase in the relaxation time, coming close to the best experimental conditions. We conclude by discussing the relationship between the observed lengthscale and various models of the relaxation time.

Tuesday, March 3, 2015 5:45PM - 6:45PM –
Session K44 GSNP: GSNP Business Meeting 214D -

5:45PM K44.00001 GSNP BUSINESS MEETING –

Wednesday, March 4, 2015 8:00AM - 11:00AM
Session L3 GSNP: Topics in Statistical Physics II 002AB - Marco Mazza, Max Planck Institute for Dynamics and Self-Organization

8:00AM L3.00001 Concept of Linear Thermal Circulator Based on Coriolis forces1 . HUANAN LI, TSAMPIKOS KOTTSOS, Wesleyan University — Directional transport and the creation of non-reciprocal devices that control the flow of energy and/or mass at predefined directions have been posing always fascinating challenges. In this contribution, we show that the presence of a Coriolis force in a rotating linear lattice imposes a non-reciprocal propagation of the phononic heat carriers. Using this effect we propose the concept of Coriolis linear thermal circulator which can control the circulation of a heat current. A simple model of three coupled harmonic masses on a rotating platform allow us to demonstrate giant circulating rectification effects for moderate values of the angular velocities of the platform.

1This work was partly sponsored by a NSF DMR-1306984 grant and by an AFOSR MURI grant FA9550-14-1-0037.
Magnetically driven quantum heat engine, ENRIQUE MUNOZ, Pontificia Universidad Catolica de Chile, FRANCISCO PENA, Pontificia Universidad Catolica de Valparaiso — In analogy with classical thermodynamics, a quantum heat engine generates useful mechanical work from heat, by means of a reversible sequence of transformations (trajectories), where the “working substance” is of quantum mechanical nature. Several theoretical implementations for a quantum heat engine have been discussed in the literature, such as entangled states in a qubit, quantum mechanical implementations of the Otto cycle, and photocells. In this work [1], we propose yet a different alternative by introducing the concept of a magnetically driven quantum heat engine. We studied the efficiency of such system, by considering as the “working substance” a single nonrelativistic particle trapped in a cylindrical potential well, as a model for a semiconductor quantum dot, in the presence of an external magnetic field. The trajectories are driven by a quasi-static modulation of the external magnetic-field intensity, while the system is in contact with macroscopic thermostats. The external magnetic field modulation allows to modify the effective geometric confinement, in analogy with a piston in a classical gas.


8:24AM L3.00003 ABSTRACT WITHDRAWN —

8:36AM L3.00004 Why are all dualities conformal? Theory and practical consequences, SEYYED MOHAMMAD SADEGH VAEZI, ZOHAR NUSSEINOV, Washington University, GERARDO ORTIZ, Indiana University, Bloomington — We relate duality mappings to the “Babbage equation” $F(F(z)) = z$ with F a map linking weak to strong coupling theories. Under fairly general conditions F may only be a specific conformal transformation of the fractional linear type. This deep general result has enormous practical consequences. For example, one can establish that weak and strong coupling expansions are trivially related, i.e., one needs to generate only one of them while the other is automatically determined through a set of linear constraints. The latter partially solve or, equivalently, localize the computational complexity to a simple fraction of the coefficients, and as a bonus those relations encode non-trivial equalities between different geometric constructions. We illustrate our findings by examining various models including, but not limited to, ferromagnetic and spin-class type Ising models on hypercubic lattices.

8:48AM L3.00005 ABSTRACT WITHDRAWN —

9:00AM L3.00006 Quantifying the Effects of Noise on Diffuse Interface Models: Cahn-Hilliard-Cook equations, SPENCER PFEIFER, BASKAR GNAPATHYSUBRAMANIAN, Iowa State Univ — We present an investigation into the dynamics of phase separation through numerical simulations of the Cahn-Hilliard-Cook (CHC) equation. This model is an extension of the well-known Cahn- Hilliard equation, perturbed by an additive white noise. Studies have shown that random fluctuations are critical for proper resolution of physical phenomena. This is especially true for phase critical systems. We explore the transient behavior of the solution space for varying levels of noise. This is enabled by our massively scalable finite element-based numerical framework. We briefly examine the interplay between noise level and discretization (spatial and temporal) in obtaining statistically consistent solutions. We show that the added noise accelerates progress towards phase separation, but retards dynamics throughout subsequent coarsening.

9:12AM L3.00007 Definitions of temperature in non-extensive systems, SERGIO DAVIS, GONZALO GUTIERREZ, Departamento de Física, Facultad de Ciencias, Universidad de Chile — Superstatistics (Beck and Cohen, 2003) is a proposed formalism for explaining the presence of non-Boltzmann distributions in Nature for systems out of equilibrium. The superstatistical ensemble is a superposition of canonical ensembles according to

$$P(\vec{r}, \beta | H) = \int_{0}^{\infty} d\beta P(\beta | H) \exp\left(-\beta H(\vec{r}, \beta)\right)/Z(\beta),$$

with $P(\beta | H)$ the probability density for the inverse temperature parameter $\beta$. In this work we show that, in order for this formalism to be internally consistent, it is impossible to have a definition of $\beta$ as an observable which is valid across all “superstatistical” ensembles. In other words, the shape of the ensemble cannot be determined by measuring temperature, only by measuring energy. Our results also reveal the fact that energy and temperature are not in the same footing as observables for non-canonical ensembles.

9:15AM L3.00008 Non-reciprocal acoustic transport in media with spectral asymmetry and losses, ANDREA KLEEMAN, RAHUL DEORA, HUANAN LI, FRED ELLIS, TSAMPIKOS KOTTOS, Department of Physics, Wesleyan University, Middletown CT-06459, USA, ILYA VITEBSKIY, The Air Force Research Laboratory, Sensors Directorate, Wright Patterson AFB, OH 45433 USA — We propose a novel scheme for scaling exponent relating morphology metrics with the level of noise. We observe a very clear scaling effect of finite domain size, which is observed to be offset by increasing levels of noise. Domain scaling reveals a clear microstructural asymmetry at various stages of the evolution for lower noise levels. In contrast, higher noise levels tend to produce more uniform morphologies.

9:24AM L3.00009 Non-reciprocal acoustic transport in media with spectral asymmetry and losses, ANDREA KLEEMAN, RAHUL DEORA, HUANAN LI, FRED ELLIS, TSAMPIKOS KOTTOS, Department of Physics, Wesleyan University, Middletown CT-06459, USA, ILYA VITEBSKIY, The Air Force Research Laboratory, Sensors Directorate, Wright Patterson AFB, OH 45433 USA — We propose a novel scheme for scaling exponent relating morphology metrics with the level of noise. We observe a very clear scaling effect of finite domain size, which is observed to be offset by increasing levels of noise. Domain scaling reveals a clear microstructural asymmetry at various stages of the evolution for lower noise levels. In contrast, higher noise levels tend to produce more uniform morphologies.

9:29AM L3.00010 Density of Yang-Lee zeros in the thermodynamic limit using Tensor RG, ARTUR GARCIA-SAEZ, TZU-CHIEH WEI, Yang Institute for Theoretical Physics and Department of Physics and Astronomy, Stony Brook University — The partition function of ferromagnets in a lattice is represented as a Tensor Network and efficiently contracted using an iterative RG process. The density of Yang-Lee zeros on the complex field plane is obtained from accurate calculations of the free energy and local observables in an effective thermodynamic limit.

9:36AM L3.00009 Density reconstruction via maximum entropy method, AUSTIN MCDONALD, RAYMOND ATTA-FYNN, Department of Physics, University of Texas at Arlington, PARTHAPRATIM BISWAS, Department of Physics and Astronomy, The University of Southern Mississippi — We demonstrate an application of the maximum entropy principle by employing the Shannon entropy functional to reconstruct functions that are otherwise non-trivial to reproduce by existing reconstruction techniques. Specifically, we present the reconstruction of the Dirac comb by maximizing the Shannon entropy subject to the moment constraints using Monte-Carlo type and population-based approaches. The results are compared with the existing results in the literature and the convergence properties of the resulting distributions are examined in relation to the number of input moments.
and at Interfaces 214C - Zahra Fakhraai, University of Pennsylvania of Energy, Office of Science, Office of Basic Energy Sciences.

Moreover, the relation of this charge inversion phenomena with the strong correlated liquid (SCL) theory has been deeply discussed. Intriguing via standard semiconductor methods. Inversion of net surface charge at the fluid/solid interface has been observed by a novel method of open potential work in the field has focused on simple monovalent electrolytes, we report a systematic study of divalent ion transport in a well-defined nanochannel fabricated — Ion transport in nanochannels has attracted increasing attention in recent years, with potential applications ranging from ionic control and biosensing to

BEN WEINER, Department of Phyiscs, Yale University, MARK REED, Department of Electrical Engineering, Department of Applied Physics, Yale University — We study the thermalization of entanglement entropy in one-dimensional spin chains under the unitary dynamics of a nonintegrable Hamiltonian or periodic driving by Floquet operators. Using full diagonalization of the Hamiltonian matrix and the Floquet operators, we analyze the time evolution of entanglement entropy starting from various initial conditions, including initial states with entanglement in excess of the thermal equilibrium value. It is found that the thermalization of entanglement entropy is coupled to local conservation laws when approaching equilibrium, and the absence of conservation laws in the Floquet system allows the entanglement entropy to thermalize more rapidly than it does in the corresponding Hamiltonian.

10:12AM L3.00012 Phase transitions in a confined monolayer of magnetized beads, JULIEN SCHOCK-MEL, Univ de Liege — We present experimental results obtained with a model experimental system dedicated to the study of 2D phase transitions. The system is composed of millimetric beads interacting through magnetic dipole-dipole interaction. Due to the confinement, repulsive interactions tend to order the system. In addition, the system is submitted to a controlled mechanical agitation which produce an erratic motion of the beads and thus creates disorder. Controlling the competition between interaction energy and entropy, allows us to explore different structures of 2 dimensional systems. At first, the melting of a two dimensional crystal is investigated. As predicted by the KT/DW theory, a two stage melting is observed, including the so-called hexatic phase (see results in Phys. Rev. E 87, 062201 (2013)). Afterward, the behavior of binary systems is studied. In particular, the effect of the grains polydispersity on the order is analyzed.

10:24AM L3.00013 Complex Pole Approach in Thermodynamic Description of Fluid Mixtures with Small Number of Molecules, TIMUR ASLYAMOV, Moscow Inst of Phys & Tech, OLEG DINARIEV, Schlumberger Moscow Research Center — Physically consistent description of equilibrium small molecular systems requires the extension of thermodynamics. The reason is the absence of thermodynamic limit, which is mandatory for the applicability of classical thermodynamics. New theoretical method of complex pole decomposition for the statistical description of small multicomponent molecular systems is implemented. Similar approach has been previously developed and applied in nuclear physics for finite systems of nucleons. We have significantly transformed and extended the original formulation to make it work for multicomponent molecular mixtures in small systems. The aim of this research is to provide new comprehensive description of small equilibrium molecular systems with numerous scientific and industrial applications for artificial and natural materials with nanopores. Several cases for molecular systems in small cavities are studied. In particular size-dependent additional pressure for small systems is evaluated analytically and numerically. The obtained results are in correspondence to published experimental data and molecular dynamics simulations.

We characterize the bifurcation and explore the dependence of the stable time-periodic state beyond the Hopf point on the misorientation angle between the substrate surfaces, we report a transition in the asymptotic states reached by such driven island dynamics from steady to oscillatory, mediated by Hopf bifurcation. Of face-centered cubic crystals in the regime where diffusional mass transport is limited to the island edge. For islands on

10:30AM L3.00014 Heterogeneous dynamics and stretched exponential decay of spatio-temporal correlations for Coulomb-interacting particles in confined geometries, AMIT GHOSAL, BISWARUP ASH, Indian Institute of Science Education and Research-Kolkata, Mohanpur Campus, India-741252, JAYDEB CHAKRABARTI, S. N. Bose National Centre for Basic Sciences, Kolkata, India-700098 — We investigate the dynamics of Coulomb-interacting confined particles over a range of temperatures capturing the crossover from a Wigner molecule to a liquid-like phase. Dynamical signatures, derived from the Van-Hove correlations, develop pivotal understanding of the phases as well as the intervening crossover, which are inaccessible from the study of static correlations alone. The motion of the particles shows frustrations, produces heterogeneities depending on the observation time-scales and temperatures and results into a non-Gaussian behavior. The extent and nature of the departure of the behavior of spatio-temporal correlations from the conventional wisdom depends crucially on the symmetry of the confinements. In particular, we find that the decay of correlations follow a stretched-exponential form in traps that lack any symmetry. Our data offers a broad support to a theoretical model that integrates the non-Gaussian behavior arising from the convolution of Gaussian fluctuations weighted by appropriate diffusivities, consistent with local dynamics. The richness of information from the dynamic correlation will be shown to improve the understanding of melting in confined systems in a powerful manner.

10:48AM L3.00015 Current-driven complex dynamics of single-layer epitaxial islands on substrates, DWAIPAYAN DASGUPTA, DIMITRIOS MAROUDAS, University of Massachusetts Amherst — We study theoretically the current-driven dynamics of isolated single-layer epitaxial islands on crystalline substrates, which provides important guidance toward surface nanopatterning approaches based on the current-driven assembly of such islands. We develop and validate a fully nonlinear model for the islands’ driven morphological evolution on elastic substrates of face-centered cubic crystals in the regime where diffusional mass transport is limited to the island edge. For islands on (110), (100), and (111)-oriented substrate surfaces, we report a transition in the asymptotic states reached by such driven island dynamics from steady to oscillatory, mediated by Hopf bifurcation. We characterize the bifurcation and explore the dependence of the stable time-periodic state beyond the Hopf point on the misorientation angle between the applied electric field and fast edge diffusion directions, the strength of the edge diffusional anisotropy, and the island size. For islands larger than a critical size, depending on the orientation of the substrate surface, we observe fingering and necking instabilities in the island morphology. We carry out a comprehensive numerical simulation study and explore the complexity of the driven island dynamics with the variation of the problem parameters.

Wednesday, March 4, 2015 8:00AM - 11:00AM — Session L43 DPOLY GSOFT GSNP: Focus Session: Stable Glasses, Fluids Under Confinement and at Interfaces 214C - Zahra Fakhraai, University of Pennsylvania

8:00AM L43.00001 Observation of Charge Inversion and Divalent Ion Transport in Nanochannels1, XIN LI, Department of Physics, Yale University, WEIHUA GUAN, Department of Electrical Engineering, Penn State University, BEN WEINER, Department of Physics, Yale University, MARK REED, Department of Electrical Engineering, Department of Applied Physics, Yale University — Ion transport in nanochannels has attracted increasing attention in recent years, with potential applications ranging from ionic control and biosensing to energy storage and conversion. Exciting phenomena arise from the nanoscale confinement of fluids and new models are expected. While most of the previous work in the field has focused on simple monovalent electrolytes, we report a systematic study of divalent ion transport in a well-defined nanochannel fabricated via standard semiconductor methods. Inversion of net surface charge at the fluid/solid interface has been observed by a novel method of open potential measurement. Moreover, the relation of this charge inversion phenomena with the strong correlated liquid (SCL) theory has been deeply discussed. Intriguing observations from conductance measurement reveal ion-surface interactions and ion-ion correlations.

1This work was supported by Nanostructures for Electrical Energy Storage (NEES), an Energy Frontier Research Center funded by the US Department of Energy, Office of Science, Office of Basic Energy Sciences.
8:12AM L43.00002 Electrostatic effects of dielectric interfaces on confined electrolyte, YUFEI JING, Applied Physics Program, Northwestern University, Evanston, IL 60208, VIKRAM JADHAO, Department of Physics & Astronomy, Johns Hopkins University, Baltimore, MD 21218, JOS W. ZWANIKKEN, MONICA OLVERA DE LA CRUZ, Department of Materials Science and Engineering, Northwestern University, Evanston, IL 60208 — The behavior of ions in liquids confined between interfaces characterized by different dielectric permittivities is crucial to many nanoscale assembly processes in synthetic and biological materials. The presence of multiple interfaces and associated dielectric heterogeneities often complicates computing the desired ionic distributions via simulations or theory. Electrostatic correlation effects in a system with electrolyte confined by two planar dielectric interfaces are systematically studied by Car-Parrinello molecular dynamics simulations and liquid state theory. Results for ionic density profiles for various electrolyte concentrations, stoichiometric ratios and dielectric contrasts are presented. We also investigate the interactions between two planar surfaces and effects of the dielectric interfaces on the double layer structure near the interfaces which lies at the heart of soft matter physics.

8:24AM L43.00003 Squeezout of a model ionic liquid under confinement and charging1.1, ERIO TOSATTI, SISSA and ICTP, Trieste, Italy, ROSARIO CAPOZZA, SISSA, Trieste, Italy, ANDREA BENASSI, Empa, Duendorf, Switzerland, ANDREA VANOSSEI, CNR-IOM Democritos and SISSA, Trieste, Italy — Electrical charging of parallel plates confining a model ionic liquid down to nanoscale distances yields a variety of charge-induced changes in the structural features of the confined liquid, including even-odd switching of the structural layering, and important changes of planar ordering within layers. By means of molecular dynamics simulations, we explore this variety of phenomena in the simplest charged Lennard-Jones coarse-grained model including the effect a neutral tail attached to one of the model ions. Using open, grand-canonical-like conditions which allow the flow of ions in and out of the interplate gap, we simulate the liquid squeezout and obtain the distance dependent forces between the plates during their adiabatic approach under load. Effective free energy curves obtained by integration of these forces versus interplate distance show the local minima that correspond to squeezing, and predict the switching between one and another under squeezing and charging.

1.1Partly sponsored under SNSF Sinergia grant CRSII2 136287/1, EU ERC grant No. 320796 MODPHYSFRICT, EU COST Action MP1303.

8:36AM L43.00004 Electrical charging effects on sliding lubrication properties of a model confined ionic liquid, ROSARIO CAPOZZA, International School for Advanced Studies (SISSA), Via Bonomea 265, 34136 Trieste, Italy, ANDREA BENASSI, Empa, Materials Science and Technology, Überlandstrasse 129, 8600 Dübendorf, Switzerland, ANDREA VANOSSEI, CNR-IOM Democritos National Simulation Center, Via Bonomea 265, 34136 Trieste, Italy, ERIO TOSATTI, International School for Advanced Studies (SISSA), Via Bonomea 265, 34136 Trieste, Italy — Ionic liquids lubricants, used under conditions of nanometric confinement between parallel plates or tip-surface gaps, explore the dependence of friction upon charging, suggestive of some electrical control of friction. Using a simple ionic liquid model, we first study by molecular dynamics the friction the between parallel plates under conditions of successive electrical charging reached by squeezout under an increasing inter-plate force. We then simulate the frictional changes brought about by different charging states of the plates, related to charging-induced switches corresponding to squeezout (or suck-in) transitions between different layering states as predicted by local minima in the charge-dependent enthalpy curves. Although the actual frictional behavior obtained does depend upon the assumed features and parameters of the model liquid and its interaction with the plates, the broader scenario obtained for charging effects, its relationship to the equilibrium layering and its enthalpy characterization appear of general value.

8:48AM L43.00005 Crossover in the local diffusive dynamics of equilibrium and supercooled confined fluids, JONATHAN BOLLINGER, THOMAS TRUSKETT, University of Texas at Austin — Confined fluids are ubiquitous in natural and technological contexts, and relating emergent structural motifs to dynamics is critical to facilitate the inverse design of nano- and micro-fluidic systems. Crucially, such thin film systems are frequently tuned between equilibrium and glassy states, as during, e.g., processing of polymer thin films. We use molecular dynamics simulations and a Fokker-Planck equation based method to examine the position-dependent diffusive dynamics of binary hard-sphere fluids confined to slit pores that are designed to mimic realizable thin films [Nugent et al. PRL 2007, 99]. At moderate densities, local single-particle mobilities normal to the direction of confinement are higher in regions of high local packing fraction. However, as the average packing fraction is increased into the supercooled regime, this local positive correlation between packing fraction and mobility is reversed. We discuss the outlook for a universal mechanistic framework that can unite these disparate local correlations between packing and mobility and also predict average diffusivities of the inhomogeneous fluids. Auxiliary measurements of the simulated films suggest that this behavioral dichotomy should also emerge in structurally similar experimental colloidal suspensions.

9:00AM L43.00006 Geometrical frustration and correlated capillary instabilities among concentric polymer toroids, ZHENG ZHANG, Univ of Colorado - Boulder, GENE HILTON, National Institute of Standards and Technology, YIFU DING, Univ of Colorado - Boulder — We present the first study on the simultaneous capillary instability among concentric viscous toroids. An array of concentric polystyrene (PS) toroids were lithographically fabricated with a constant radial spacing between neighboring toroids. The toroids were confined in a poly (methyl methacrylate) (PMMA) matrix. PS and PMMA were used because of their immiscibility and well-characterized physical properties. The glass transition temperature (T_g) of the pattern are well above room temperature. We found that the radial contraction mode of toroids (Pairam & Fernández-Nieves, PRL 2009) was inhibited due to substrate confinement. Upon further annealing, the toroids ruptured along the circumferential direction at a finite wavelength. Depending on the relative volume of PS, the rupture behavior of each toroid (with different aspect-ratios) can be non-correlated or correlated radially. In the correlated case, geometric frustration due to the toroidal curvature was observed, which led to an intriguing branching behavior in the correlated instability and closely resembles a Cayley tree with fractal coordination number of 3.

9:12AM L43.00007 Ultrastable Glasses and the Random First Order Transition Theory of Glasses, PETER WOLYNES, Rice University — I will discuss the implications of the RFT theory for the dynamics of ultrastable glasses focusing on the achievable limits to stability and the heterogeneous and homogeneous mechanisms of their rejuvenation.

9:48AM L43.00008 Probing the Dynamics of Thin TPD Glass Films via Dewetting, YUE ZHANG, ETHAN GLOR, TIANYI LIU, CHEN LI, ZAHRA FAKHRAAI, Department of Chemistry, University of Pennsylvania — Enhanced mobility of surface layers has been observed in both polymer glasses and small molecule organic glasses. In polymers, the mobile surface layer is believed to have great effects on the properties of thin films. Similar studies in small molecule glasses are significantly more challenging due to dewetting Understanding the dynamics of this mobile layer, and its effect on thin film dynamics can be important in understanding heterogeneous dynamics in glassy systems. In this work, we investigate the properties of the mobile layer and its effect on the overall properties of thin glass films of small molecule organic glasses. We show that thin (thickness below 30nm) TPD (N,N'-Bis(3-methylphenyl)-N,N'-diphenylbenzidine) films prepared by physical vapor deposition (PVD), can be unstable and dewet in a hole growth manner due to enhanced mobility at temperatures as low as T_g-35K. By following the kinetics of dewetting, we investigate the mobility changes with temperature and film thickness. These studies can elucidate the relation between the enhanced mobility and the stability of thick films of the same materials prepared at similar deposition temperatures and thus the formation mechanisms and unique properties of physical vapor deposited glasses.

1Department of Chemistry, University of Pennsylvania; National Science Foundation
10:00AM L43.00009 Dewetting of a Liquid-Liquid System. STEFAN BOMMER, NIKOLAS BECKER, Experimental Physics, Saarland University, 66041 Saarbruecken, Germany, SEBASTIAN JACHALSKI, DIRK PESCHKA, Weierstrass Institute for Applied Analysis and Stochastics, 10117 Berlin, Germany, BARBARA WAGNER, Institute for Mathematics, Technical University Berlin, 10623 Berlin, Germany, RALF SEEMANN, Experimental Physics, Saarland University, 66041 Saarbruecken, Germany — In recent years a thorough understanding of thin film dewetting from solid substrates was developed. However, the understanding of a thin liquid film dewetting from another liquid remained scarce. By in situ AFM studies we explore the dewetting dynamics and the morphologies of liquid polystyrene (PS) dewetting from liquid poly(methyl-methacrylate) (PMMA). Using a selective solvent allows to remove the dewetted PS layer and to image the liquid/liquid interface at selected times. Combining the PS/air and the PS/PMMA interfaces we obtain the full three dimensional shape of the dewetting morphologies. The characteristic shapes of the rim profiles, the equilibrating droplets and their dewetting dynamics depend not only on the ratios of viscosity and surface tension of the two liquids but also on the relative film height of the underlying liquid. The latter originates from the flow field of the dewetting liquid which penetrates surprisingly deep into the lower liquid it is dewetting from.

10:12AM L43.0010 Coupling the coffee-ring effect to phase separation in drying polymer-nanocrystal deposits. ERIK K. HOBBIE, NDSU, JOSEPH B. MILLER, Rice University, AUSTIN C.P. USSELMAN, NDSU, REBECCA J. ANTHONY, UWE R. KORTSHAGEN, UMN, ALEXANDER J. WAGNER, ALAN R. DENTON, NDSU — The coupling between the coffee-ring effect and liquid-liquid phase separation is examined for ternary mixtures of solvent, polymer and colloidal nanocrystal. Using real-space imaging and spectroscopic techniques, we find experimental evidence that the characteristic features of the rim profiles, the equilibrating droplets and their dewetting dynamics depend not only on the ratios of viscosity and surface tension of the two liquids but also on the relative film height of the underlying liquid. The latter originates from the flow field of the dewetting liquid which penetrates surprisingly deep into the lower liquid it is dewetting from.


1NSF (DRM-1206724, DMREF-1234320)

Wednesday, March 4, 2015 8:00AM - 11:00AM Session L44 GSNP: Focus Session: Systems far from Equilibrium II 214D - Michel Pleimling, Virginia Polytechnic Institute and State University

8:00AM L44.00001 Extremes in systems with linear and nonlinear memory by the return-interval approach. ARMIN BUNDE, Institute of Theoretical Physics, Giessen University — The occurrence of extreme events above a certain threshold $Q$ in time series can be characterized by their return intervals $r_i$. Here we review recent work on the distribution $P_Q(r)$ of the return intervals and their correlation properties (i) in systems with linear long-term memory and (ii) in systems with non-linear memory. Examples for (i) are temperature records, examples for (ii) are financial records. The distribution of the return intervals is an important quantity in risk estimation since it enables one to calculate the probability that an extreme event occurs in the next period of time. We discuss the different functional forms of $P_Q(r)$ that range from simple exponential (random systems) to stretched exponentials (systems with long-term memory) and $q$-exponentials (systems with non-linear memory). We show that both linear and non-linear memory lead to long-term memory in the return intervals, which then results in a clustering of the extreme events. Both the distribution of the return intervals and their correlation properties can be used as a test bed for computer models.

2This work has been supported by the Deutsche Forschungsgemeinschaft

8:36AM L44.00002 Rare Event Extinction on Stochastic Networks. IRA SCHWARTZ, Naval Research Lab, LEAH SHAW, College of William and Mary, BRANDON LINDLEY, R. D. Wagner Associates, Inc. — We consider the problem of extinction processes on random networks with a given structure. For sufficiently large well-mixed populations, the process of extinction of one or more state variable components occurs in the tail of the quasi-stationary probability distribution, thereby making it a rare event. Here we show how to extend the theory of large deviations to random networks to predict extinction times. In particular, we use the theory to find the most probable path leading to extinction. We apply the methodology to epidemic models and discover how mean extinction times scale with epidemiological and network parameters in Erdos-Renyi networks. The results are shown to compare quite well with Monte Carlo simulations of the network in predicting both the most probable paths to extinction and mean extinction times.

1BL was a National Research Council post doctoral fellow. IBS was supported by NRL base funding and ONR. LIB was supported by the ARO, AFOSR, and NIH.

2Nonlinear Systems Dynamics Section

8:48AM L44.0003 Revealing non-Gaussian noise through noise-induced switching in a parametric oscillator. PAVEL POLVIN, Michigan State University, PANPAN ZHOU, Hong Kong University of Science and Technology, NICHOLAS MILLER, SiTime, STEVEN SHAW, Michigan State University, HO BUN CHAN, Hong Kong University of Science and Technology, MARK DUKMAN, Michigan State University — Rates of noise-induced switching between coexisting states of dynamical systems exponentially strongly depend on the noise characteristics. We use the related sensitivity to reveal the deviation of the noise from Gaussian. We study a parametrically driven nonlinear oscillator, which has two stable states of forced vibrations at half the frequency $\omega_F$ of the driving field. The states are identical, except that they are shifted in phase by $\pi$. Noise causes switching between the states. A stationary noise leads to a stationary distribution over the states. If the noise is Gaussian and coordinate-independent, the probability densities of noise pulses of the opposite polarities are the same. As a result, the state populations are equal. The difference of the state populations is an indication of non-Gaussian noise. We illustrate the effect for a sinusoidal signal at frequency $\omega_F/2$ modulated by Poisson-distributed pulses. We show, theoretically and through the experiment with a micro-electro-mechanical system, that the population difference is highly sensitive to the rate and amplitude of the pulses and displays a characteristic nonmonotonic dependence on the pulse rate. The theory is in quantitative agreement with the experiment.
bHc by means of suitable growth sequences and deposition conditions [1]. For the dynamic field response experiments, we utilized a home-built high-sensitivity complications due to long-range magneto-static interactions. Correspondingly, we have grown 30 nm thick Co-films that exhibit (10-10) surface orientation an oscillating magnetic field. For our experiments, we have used Co-films with in-plane orientation of the uniaxial magneto-crystalline anisotropy axis to avoid time dependent magnetic reversal behavior of uniaxial films in the vicinity of the dynamic phase transition (DPT) as a function of the period P and bias Hb. 

Films, ANDREAS BERGER, OLATZ IDIGORAS, CIC nanoGUNE, PAOLO VAVASSORI, CIC nanoGUNE and IKERBASQUE Foundation — We studied the ocean heat content. as specific examples – in the context of both exactly solvable models (based on linear Langevin equations with additive white noise) and physical data of global ocean heat content.


9:12AM L44.00005 Noise Induced Switching and Extinction in Systems with Delay1 LORA BILLINGS, Montclair State University, IRA SCHWARTZ, US Naval Research Laboratory, TOM CARR, Southern Methodist University, MARK DYKMAN, Michigan State University — We consider the rates of noise-induced switching between multiple attractors of dynamical systems with delay, and the rates of noise-induced extinction in delayed systems modeling population dynamics. In the weak noise limit, the rates of inter-attractor switching and extinction are exponentially small. To logarithmic accuracy, the formulation of the rates is reduced to variational problems, which give the most probable paths followed in both switching or extinction dynamics. We show that the equations for the most probable paths are acausal and formulate the appropriate boundary conditions. Explicit general results of the rates are obtained for small delay compared to the relaxation rate, and verified using a direct variational method to find the rates. We find that the analytical results agree well with the numerical simulations for both switching and extinction rates.

1Supported by ARO, DARPA, NSF, and ONR.

9:24AM L44.00006 Probability current loops in non-equilibrium steady states and statistical properties of angular momenta in configuration space1 R.K.P. ZIA, Physics Dept, Virginia Tech, Blacksburg, VA, BAYLOR FOX-KEMPER, Department of Geological Sciences, Brown University, Providence, RI, DIBYENDU MANDAL, JEFFREY WEISS, Department of Atmospheric and Oceanic Sciences, University of Colorado, Boulder, CO — Unlike systems in thermal equilibrium, steady probability current loops persist in non-equilibrium stationary states. One of the consequences is that, in the space of two or more observable quantities (qi), the average “angular momentum” (⟨b⟩i ≡ ⟨qi × qj⟩) is typically non-trivial. In addition, the full distribution of L often display remarkable properties. We will provide a general framework for the study of L, as well as specific examples – in the context of both exactly solvable models (based on langevin equations with additive white noise) and physical data of global ocean heat content.

1Supported in part by NSF grants DOS-1245944 and DMR-1244660

9:36AM L44.00007 Experimental Observation of Dynamic Phase Transitions in uniaxial Co-Films ANDREAS BERGER, OLATZ IDIGORAS, CIC nanoGUNE, PAOLO VAVASSORI, CIC nanoGUNE and IKERBASQUE Foundation — We studied the time dependent magnetic reversal behavior of uniaxial films in the vicinity of the dynamic phase transition (DPT) as a function of the period P and bias Hb of an oscillating magnetic field. For our experiments, we have used Co-films with in-plane orientation of the uniaxial magneto-crystalline anisotropy axis to avoid complications due to long-range magneto-static interactions. Correspondingly, we have grown 30 nm thick Co-films that exhibit (10-10) surface orientation by means of suitable growth sequences and deposition conditions [1]. For the dynamic field response experiments, we utilized a home-built high-sensitivity magneto-optical Kerr effect setup, which allowed for real-time low-noise hysteresis loop measurements with P as small as 0.580 ms. Our experiments reveal in addition to the DPT at a critical period Pc, the occurrence of transient dynamic behavior for P < Pc [2]. Our data are consistently explained by a phase line at Hb = 0 for P < Pc, which causes a first order phase transition in between two antiparallel dynamic order states, thus indicating far-reaching similarities of the DPT to equilibrium phase transitions [2]. However, we also observe anomalies, such as unusual fluctuation pattern in the Pc plane, which might be related to the recently suggested occurrence of dynamically “dead” surfaces [3]. References: [1] O. Idigoras et al., J. Appl. Phys. 115, 083912 (2014); [2] A. Berger et al., Phys. Rev. Lett. 111, 190602 (2013); [3] H. Park and M. Pleimling, Phys. Rev. Lett. 109, 175703 (2012).

9:48AM L44.00008 Effects of magnetic field quenches on the relaxation dynamics of vortex lines in disordered type-II superconductors1 HIBA ASSI, HARSHWARDHAN CHATURVEDI, MICHEL PLEIMLING, UWE C. TÄUBER, Department of Physics, Virginia Tech, ULIRCH DOBRAMYSŁ, Mathematical Institute, University of Oxford — Understanding the relaxation dynamics of vortex matter in disordered type-II superconductors from experimentally realizable initial conditions may improve material characterization and optimization for technological applications. We model magnetic flux lines in the London limit as interacting directed elastic lines subject to uncorrelated point-like or extended columnar pinning centers. We employ a Langevin Molecular Dynamics algorithm to simulate the vortex dynamics. We analyze the vortex relaxation kinetics following sudden magnetic field changes by instantaneously adding or removing lines from the system at random. By studying two-time correlation functions such as the mean-square displacement and height autocorrelation function, as well as one-time observables such as the ratio of pinned line elements and radius of gyration, we disentangle the effects of the competing repulsive vortex interaction and pinning and we compare the distinct relaxation properties due to the type of disorder. We discovered some universal features regardless of the type of quench and the presence of vortex interactions, and others that are dependent on the type of disorder and the system's initial conditions.

1Research supported by the U.S. Department of Energy, Office of Basic Energy Sciences, Division of Materials Sciences and Engineering under Award DE-FG02-09ER46613.

10:00AM L44.00009 Pinning time statistics for vortex lines in disordered environments1 UWE C. TÄUBER, Department of Physics, Virginia Tech, ULIRCH DOBRAMYSŁ, University of Oxford, MICHEL PLEIMLING, Department of Physics, Virginia Tech — We study the pinning dynamics of magnetic flux (vortex) lines in a disordered type-II superconductor. Using numerical simulations of a directed elastic line model, we extract the pinning time distributions of vortex line segments. We compare different model implementations for the disorder in the surrounding medium: discrete, localized pinning potential wells that are either attractive or repulsive or purely attractive, and whose strengths are drawn from a Gaussian distribution; as well as continuous Gaussian random potential landscapes. We find that both schemes yield power law distributions in the pinned phase as predicted by extreme-event statistics, yet they differ significantly in their effective scaling exponents and their short-time behavior.

1This research is supported by the U.S. Department of Energy, Office of Basic Energy Sciences, Division of Materials Sciences and Engineering under Award DE-FG02-09ER46613.
10:12AM L44.00010 Dead magnetic surface layers near dynamic phase transitions. PATRICIA RIEGO, ANDREAS BERGER, CIC nanGUNE Consolidor — We have performed a detailed study of the dynamic phase transition (DPT) for a magnetic layer system with surfaces subjected to an oscillatory external magnetic field in mean field approximation (MFA). Specifically, we focused our study on bulk-terminated surfaces, i.e., we deal with multilayer systems that have the same exchange coupling strength between nearest neighbors everywhere, including at the surface. We are able to reproduce within the MFA the absence of a surface phase transition at the bulk critical point that was previously reported by Tauscher et al., utilizing Monte-Carlo simulations [1]. In addition, we observe that the DPT is also absent or at least severely suppressed for several layers below the surface, which exhibit susceptibility peaks that are four orders of magnitude smaller than the one corresponding to the bulk. Most importantly, we identify the reason for this "dead" surface behavior. The oscillatory magnetization $M(t)$ response to the external magnetic field is not synchronous in between the surface and the bulk near the DPT. This lack of correlation prevents the layers from sufficiently supporting each other's dynamic ordering, so that the surface and the layers close to it cannot follow the bulk DPT.


10:24AM L44.00011 Spherical surface growth models. XAVIER DURANG, Korean Institute for Advanced Study, MALTE HENKEL, Universite de Lorraine, France — We study several surface growth models obtained by treating and replacing the non-linear term in the noisy Burgers equation or the KPZ equation by a mean spherical condition. We want to explore the consequences of such constraints on the Edwards-Wilkinson (EW) interface. In those exactly solvable models, one has to solve the spherical conditions and then we can derive the two-time quantities (the correlation function and the response function). Therefore, we have access to the non-equilibrium exponents and compare them to those of the EW model or the KPZ model.

10:36AM L44.00012 Failure of Steady State Thermodynamics1. RONALD DICKMAN, Universidade Federal de Minas Gerais — To be useful, steady state thermodynamics (SST) must be self-consistent and have predictive value. Consistency of SST was recently verified for driven lattice gases under global weak exchange. Here, I verify consistency of SST under local (pointwise) exchange, but only in the limit of a vanishing exchange rate; for a finite exchange rate the coexisting systems have different chemical potentials. I consider the lattice gas with nearest-neighbor exclusion on the square lattice, with nearest-neighbor hopping (NNE dynamics), and with hopping to both nearest and next-nearest neighbors (NNE2 dynamics). I show that SST does not predict the coexisting densities under a nonuniform drive, or in the presence of a nonuniform density provoked by a hard wall or nonuniform transition rates. The steady state chemical potential profile is, moreover, nonuniform at coexistence, contrary to the basic principles of thermodynamics. Finally, I discuss examples of a pair of systems possessing identical steady states, but which do not coexist when placed in contact. These results cast serious doubt on the consistency and predictive value of SST.

1Supported by CNPq, Brazil

10:48AM L44.00013 Self-organization in non-equilibrium systems1. GEORGI GEORGIEV, Assumption College, GERMANO IANNACCHIONE, WPI — The question about why complex systems self-organize to reach more efficient and robust states is still without a satisfactory answer. We approach it from a physics perspective, where energy gradients lead to change in the structure of systems to ensure the most efficient energy transport. This approach stems from fundamental variational principles in physics, such as the principle of least action, which determine the motion of particles. We compare energy transport through a cell which has random motion of its molecules, and a cell which can form convection cells. We examine the energy transport. This approach is motivated by the existence of minimal energy states under a given boundary conditions, which is the case in the presence of a nonuniform drive, or in the presence of a nonuniform density provoked by a hard wall or nonuniform transition rates. The steady state chemical potential profile is, moreover, nonuniform at coexistence, contrary to the basic principles of thermodynamics. Finally, I discuss examples of a pair of systems possessing identical steady states, but which do not coexist when placed in contact. These results cast serious doubt on the consistency and predictive value of SST.

1WPI, Assumption College

Wednesday, March 4, 2015 8:00AM - 11:00AM —
Session L49 GSOFT GSNP: Focus Session: Mechanics of Defects and Discontinuities 217D -
James Hanna, Virginia Polytechnic Institute and State University

8:00AM L49.00001 Fracture of brittle coatings on soft plastic substrates. JOEL MARTHELOT, Massachusetts Institute of Technology, DAVY DALMAS, JEREMIE TEISEISSE, SVI, CNRS, Saint-Gobain, JOSE BICO, BENOIT ROMAN, PMMH, ESPCI ParisTech — Mechanics of stiff and electrically conductive films deposited on soft plastic substrates have recently gain interest due to the development of stretchable electronics applications. When submitted to tensile stress, such films tend to fail with the apparition of arrays of parallel channel cracks transverse to the direction of deformation, with fatal consequences for electrical conductivity. We study the propagation of such fractures in oxide monolayers coated on a polymer substrate under uniaxial stretching. We show how the crack density undergoes a transition from a statistic failure distribution of brittle material to a deterministic failure set by the elastic mismatch between the film and the substrate. A two-dimensional model of a film bonded to an elastic substrate fails to describe the saturation observed at high strain. We present experimental evidences of the localization of strain in the substrate by in-situ AFM imaging of the fracture process. We propose an increment of the model to account for the plasticity of the substrate. This description allows to pass continuously from the elastic to the plastic regime and to predict the saturation of the fragmentation as observed experimentally at large deformation.

8:12AM L49.00002 ABSTRACT WITHDRAWN —

8:24AM L49.00003 Effect of topological defects and curvature on anisotropic crystal growth. AMIR AZADI, Department of Physics, University of Massachusetts, Amherst, GREGORY M. GRASON, Department of Polymer Science and Engineering, University of Massachusetts, Amherst — The equilibrium shapes and symmetries of crystals are vestiges of the physical principles underlying their formation. We perform particle-based simulations guided by analytical analysis to investigate the structure of crystalline domains on curved substrates, a focus on the impact of topological defects on domain morphology. We find at low area fraction, as has been argued previously, that isotropic crystal growth with relatively compact domains generates large curvature-induced strains accommodated by relative ductile interactions, while the formation of anisotropic ribbon-like structures with lower-curvature induced stresses, introduces a larger line tension cost, and is thus favored for brittle crystals. Our results show that for ductile crystals with large surface coverage, appearance of stable topological defects precludes the formation of anisotropic, ribbon domains. However branch-like structures with large interfacial area are stable for certain values of intermediate curvature and crystalline ductility. These processes are guided by the interplay between elastic shape instability, defects, and curvature, where pattern formations are not related to kinetic instabilities.
8:36AM L49.00004 Energy Barriers for Defects in Disordered Solids, SVEN WIJTMANS, LISA MANNING, Syracuse University — In solids, defects govern flow and failure. In crystals, defects are easily-identified dislocations, while in disordered solids, defects can be found by analyzing the vibrational modes of the system, which are eigenvectors of the matrix describing the linear response. The low frequency modes are typically quasi-localized hybrids of excitations localized at the defects and plane-wave-like modes. Additional analysis can separate these components, giving the location of a defect and displacement of particles along that defect. To define an energy barrier for each defect, we displace particles along an isolated defect mode and calculate the energy at which the system transitions to a new energy basin. Different definitions of a new basin, such as a change in the particle contact network or particle displacements above a specific threshold, give different results. We identify several criteria that are consistent and provide a reasonable, robust definition of an energy barrier. Somewhat surprisingly, we find that energy barriers for isolated defects are generally higher than energy barriers for typical quasi-localized modes in the system.

8:48AM L49.00005 Tuning a material’s properties through the excitation of localized defect modes, MARC SERRA GARCIA, ETH Zurich, JOSEPH LYDON, California Institute of Technology, CHIARA DARAIIO, ETH Zurich — Technological applications such as acoustic super-lenses and vibration mitigation devices require materials with extreme mechanical properties (Very high, zero, or negative stiffness). These properties can be achieved through buckling instabilities, local resonances and phase transitions, mechanisms that are limited to particular frequencies, strains or temperatures. In this talk I will present an alternative mechanism to tune the stiffness of a lattice. The mechanism is based on the excitation of a nonlinear localized defect mode. The oscillation of the defect mode affects the bulk properties of the lattice. This is due to the thermal expansion of the defect mode and the nonlinear coupling between the mode amplitude and the strain of the lattice. Due to the singular properties of nonlinear systems near bifurcation points, the lattice can achieve an arbitrarily large stiffness. It is possible to select point of the force-displacement relation that is being tuned by selecting the defect’s excitation frequency and amplitude. Depending on the nonlinear interaction potential at the defect site, the stiffness can be tuned to extremely positive or extremely negative values. While our theoretical and experimental results have been obtained in a granular crystal, the analysis suggests that an equivalent effect should be present in other lattices with localized modes and nonlinearity.

9:00AM L49.00006 Scars and the stability of crystalline shells under external pressure, DUAN-DUAN WAN, MARK BOWICK, Syracuse University, RASTKO SKNEPNEK, University of Dundee — While continuum elastic theory predicts the mechanical properties of ideal spherical shells under external pressure, on microscopic scale the response of shells to pressure may be affected by their crystalline order and defect structure. Here we compare the stability, under external pressure, of shells with a minimal set of topologically-required defects to shells with extended defect arrays (a “star of bars”). In particular, we perform Monte Carlo simulations to compare how shells with and without scars deform quasi-statically under external hydrostatic pressure. We find that the critical pressure at which shells collapse is lowered when the scar distribution breaks icosahedral symmetry and raised when symmetry is preserved. The particular shapes resulting from collapses which break icosahedral symmetry depend crucially on the Föppl-von Kármán number.

9:12AM L49.00007 Dynamics and geometry of interacting fractures in torn elastic sheets: convergent, divergent, and multiple swirling cracks, EUGENIO HAMM, Universidad de Santiago de Chile — I will present some recent results on the dynamics of multiple interacting cracks in torn elastic sheets. Specifically, I will consider a peeling-like configuration, in which two cracks converge in a robust fashion, and a “concertina” configuration in which two cracks systematically diverge. Based on experiments, I will discuss the non-trivial aspects of both problems, namely the way in which elasticity and fracture mechanics are concomitant when it comes to predict crack paths. Besides, I will show cases in which the trajectory of a crack is dictated by the path followed by another crack. This delayed interaction of cracks allows the construction of multiple crack configurations in which each crack recursively interacts with a nearby crack, giving rise to divergent self-similar spiral trajectories. Finally, I will discuss the effect of material anisotropy on the propagation of cracks. If time permits, I will also present a concise review of a second example of defect dynamics: the motion of conical singularities in thin elastic sheets, subjected to external forcing, and their mutual interaction. Specifically I will consider the gliding, climbing, annihilation and rotation of such structures.

9:48AM L49.00008 Untangling Superfluid Vortices, DUSTIN KLECKNER, MARTIN W. SCHEELEER, University of Chicago, DAVIDE PROMENT, University of East Anglia, WILLIAM T. M. IRVINE, University of Chicago — What is the role of topology, or knottedness, in superfluid phase defects (quantum vortices)? In ideal classical fluids, vortex knots may never untie, and so there is an associated conserved quantity — helicity — which measures how tangled a flow is. One might expect a similar robustness for superfluid defects, however, simulations of the Gross-Pitaevskii equation demonstrate that vortex knots and links spontaneously untie and unlink. Nonetheless, the topology dramatically affects the vortex evolution, and a component of the initial measure how tangled a flow is. One might expect a similar robustness for superfluid defects, however, simulations of the Gross-Pitaevskii equation demonstrate that vortex knots and links spontaneously untie and unlink. Different definitions of a new basin, such as a change in the particle contact network or particle displacements above a specific threshold, give different results. We identify several criteria that are consistent and provide a reasonable, robust definition of an energy barrier. Somewhat surprisingly, we find that energy barriers for isolated defects are generally higher than energy barriers for typical quasi-localized modes in the system.

10:00AM L49.00009 Dynamics of vacancies in two-dimensional Lennard-Jones crystals, ZHENWEI YAO, MONICA OLVERA DE LA CRUZ, Northwestern University — Vacancies represent an important class of crystallographic defects, and their behaviors can be strongly coupled with relevant material properties. We report the rich dynamics of vacancies in two-dimensional Lennard-Jones crystals in several thermodynamic states. Specifically, we numerically observe significantly faster diffusion of the 2-point vacancy with two missing particles in comparison with other types of vacancies; it opens the possibility of doping 2-point vacancies into atomic materials to enhance atomic migration. In addition, the resulting excitations in the healing of a long vacancy suggest the intimate connection between vacancies and topological defects that may provide an extra dimension in the engineering of defects in extensive crystalline materials for desired properties.

10:12AM L49.00010 Jump conditions for thin bodies from an action principle, JAMES HANNA, Virginia Polytechnic Institute and State University — Thin, flexible bodies such as strings, sheets, and rods often sustain kink geometric features, or experience discontinuous contact forces in their interactions with obstacles. The physics of dynamic and static versions of these phenomena differ. Kink/shock propagation, impact, peeling, unwrapping, tearing and cracking all occur at geometric locations in a body that do not correspond to material points. I will discuss how the jump conditions for momentum and energy across such moving discontinuities may be derived from an action principle for an extended body with time-dependent, non-material boundaries.

10:24AM L49.00011 ABSTRACT WITHDRAWN —
10:36AM L49.00012 Nonlinear optical probing of electric field induced oxygen migrations in Fe doped SrTiO$_3$\textsuperscript{1}, HAOCHEN YUAN, DAVID ASCIENZO, ONUR KURT, ZEHRA CEVHER, STEVE GREENBAUM, CUNY-Hunter Coll, RUSSELL MAIER, CLIVE RANDALL, the Pennsylvania State University, YUHANG REN, CUNY-Hunter Coll. CENTER FOR DIELECTRIC STUDIES, MATERIALS RESEARCH INSTITUTE TEAM — We report on our recent study of the electric field induced oxygen migration dynamics and defect states near the interface in Fe-doped SrTiO$_3$ single crystals by optical second harmonic generation (SHG) using a femtosecond Ti:sapphire laser at 800 nm wavelength. By varying both the incidence and the output angles, we identified a strong correlation between the measured SHG signals and the microscopic defect textures of the samples. Significant changes in SHG intensities and phases are explained by the formation and extension of oxygen vacancies and crystalline distortions near Fe defect centers. Our results show that the SHG technique is a powerful tool for detecting local environment near interfaces and oxygen migrations in ferroelectric structures.\textsuperscript{1}

10:48AM L49.00013 Positron beam spectroscopy of defect kinetics in highly oriented pyrolytic graphite\textsuperscript{1}, VARGHESE ANTO CHIRAYATH\textsuperscript{2}, AMARENDR A G, IGCAR, Kalpakkam, India - 603102 — We report here slow positron beam spectroscopy of thermally activated defect annealing mechanisms in highly oriented pyrolytic graphite (HOPG) which has been implanted with 200 keV carbon ions. The HOPG samples were irradiated to a dose of $10^{14}$ and $10^{15}$ ions/cm$^2$ which are just below the dose required for amorphization. The open volume defect-sensitive positron studies have clearly shown a defect annealing mechanism at temperatures close to the Wigner energy release peak for both the lower and higher dose irradiated samples. The sample irradiated to higher dose has also shown a second defect annealing step at 723K from near the end of range of the implanted ions. This step however was not visible in the lower dose sample and has not been previously reported. Positron beam spectroscopy could also detect the presence of interstitial defects trapped at the inter-planar regions after the open volume defect recovery by 973 K. These results will be compared to the present understanding of the open volume defect structures and their migration in graphite as well as in other sp$^2$ hybridized nanostructures like graphene.\textsuperscript{1,2}


11:15AM M44.00001 ABSTRACT WITHDRAWN —

11:27AM M44.00002 Total cost of operating an information engine, JAEJON UM, Korea Institute for Advanced Study, HAYE HINRICHS, University of Wuerzburg, CHULAN KWON, Myongji University, HYUNGGYU PARK, Korea Institute for Advanced Study — We study a two-level system controlled in a discrete feedback loop, modeling both the system and the controller in terms of stochastic Markov processes. We find that the extracted work, which is known to be bounded from above by the mutual information acquired during measurement, has to be compensated by an additional energy supply during the measurement process itself, which is bounded by the mutual information from below. Our results confirm that the total cost to operate an information engine is in full agreement with the conventional second law of thermodynamics. We also consider the efficiency of the information engine in the finite-time case.

11:39AM M44.00003 Simulation of an epidemic model with vector transmission, ADRIANA G. DICKMAN, Pontificia Universidade Católica de Minas Gerais, RONALD DICKMAN, Universidade Federal de Minas Gerais — We study a lattice model for vector-mediated transmission of a disease in a population consisting of two species, A and B, which contract the disease from one another. Individuals of species A are sedentary, while those of species B (the vector) diffuse in space. Examples of such diseases are malaria, dengue fever, and Pierce’s disease in vineyards. The model exhibits a phase transition between an absorbing (infection free) phase and an active one as parameters such as infection rates and vector density are varied. We study the static and dynamic critical behavior of the model using initial spreading, initial decay, and quasistationary simulations. Simulations are checked against mean-field analysis. Although phase transitions to an absorbing state fall generically in the directed percolation universality class, this appears not to be the case for the present model.

11:51AM M44.00004 Equilibrium behavior of coarse-grained chaos, DAVID A. EGOLF, CHRISTOPHER C. BALLARD, C. CLARK ESTY, Dept of Physics, Georgetown University — A wide variety of systems exhibiting spatiotemporal chaos have been shown to be extensive, in that their fractal dimensions grow linearly with volume. Ruelle argued that this extensivity is evidence that these systems can be viewed as a gas of weakly-interacting regions. We have tested this idea by performing large-scale computational studies of spatiotemporal chaos in the 1D complex Ginzburg-Landau equation, and we have found that aspects of the coarse-grained system are well-described not only as a gas, but as an equilibrated gas — in particular, a Tonks gas (and variants) in the grand canonical ensemble. Furthermore, for small system sizes, the average number of particles in the corresponding Tonks gas exhibits oscillatory, decaying deviations from extensivity in agreement with deviations in the fractal dimension found by Fishman and Egolf. This result not only supports Ruelle’s picture but also suggests that the coarse-grained behavior of this far-from-equilibrium system might be understood using equilibrium statistical mechanics.

12:03PM M44.00005 How to detect many body localization in experiments, RAHUL NANDKISHORE\textsuperscript{1}, Princeton University — The standard theory of many body localization (MBL) is framed in terms of exact eigenstates of perfectly isolated quantum systems. However, exact eigenstates can neither be prepared nor measured in the laboratory, and perfectly isolated quantum systems are equally unrealizable. In this talk I explain how MBL can be reformulated without invoking exact eigenstates or perfect isolation. I introduce a way to think about MBL in terms of correlation functions of local operators, evaluated in arbitrary states. This perspective reformulates the standard theory in terms of (in principle) experimentally measurable quantities. Moreover, this “spectral” perspective on MBL is far more robust than the conventional “eigstate” perspective. Eigenstates thermalize upon arbitrarily weak coupling to an external environment, but the correlation functions (which are the physical observables) continue to show signatures of MBL as long as the coupling to the environment is weaker than the characteristic energy scales in the system Hamiltonian. I also show how this “spectral perspective” can be used to reveal additional structure in the MBL phase, and to make progress on otherwise intractable theory problems.

\textsuperscript{1}Collaborators: Sarang Gopalakrishnan, David Huse, Souika Johri, Ravin Bhatt
We present one possible unifying framework for the statistics of driven quantum systems in terms of 

\[ P(t) \sim t^{-\beta} \]

with exponent \( \beta = 1/4 \). When the two particles have diffusion constants \( D_1 \) and \( D_2 \), the exponent depends on the mobilities, \( \beta = \frac{1}{2} \arctan \sqrt{D_2/D_1} \). We also use numerical simulations to investigate maxima of multiple particles in one dimension and the largest extension of particles in higher dimensions.

We consider a question motivated by the third law of thermodynamics: Can there be a local temperature arbitrarily close to zero in a nonequilibrium quantum system? We consider ballistic quantum conductors with the source reservoir held at finite temperature and the drain held at or near absolute zero, a problem outside the scope of linear response theory. We obtain local temperatures close to absolute zero when electrons originating from the finite temperature reservoir undergo destructive quantum interference. We compute the local temperature by numerically solving a nonlinear system of equations describing equilibration of a scanning thermoelectric probe with the system, and obtain excellent agreement with analytic results derived using a method analogous to the Sommerfeld expansion.

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This work was supported by the Los Alamos LDRD program and the Deutsche Forschungsgemeinschaft.
1:39PM M44.00013 Finite N corrections to Vlasov dynamics and the range of pair interactions
ANDREA GABRIELLI, Institute of Complex Systems (ISC) - CNR (Italy), MICHAEL JOYCE, JULES MORAND, LPNHE - Univ. Paris VI “Pierre et Marie Curie” (France) — We explore [1] the conditions on a pair interaction for the validity of the Vlasov equation to describe the dynamics of an interacting N particle system in the large N limit. Using a coarse-graining in phase space of the exact Klimontovich equation for such a system, we evaluate the scalings with N of the terms describing the corrections to the Vlasov equation for the coarse-grained one particle phase space density. Considering an interaction with radial pair force $F(r) \sim 1/r^d$, regulated to a bounded behavior below a “softening” scale $l$, we find that there is an essential qualitative difference between the cases $a<d$ (i.e. the spatial dimension) and $a>d$, i.e., depending on the the integrability at large distances of $F(r)$. For $a<d$ the corrections to the Vlasov dynamics for a given coarse-grained scale are essentially insensitive to the softening parameter $l$, while for $a>d$ the corrections are directly regulated by $l$, i.e. by the small scale properties of the interaction, in agreement with the Chandrasekhar approach [2]. This gives a simple physical criterion for a basic distinction between long-range ($a<d$) and short range ($a>d$) interactions, different from the thermodynamic one ($a<d-1$ or $a>d-1$). This alternative classification, based purely on dynamical arguments, is relevant notably to understanding the conditions for the existence of so-called quasi-stationary states in long-range interacting systems.


1:51PM M44.00014 Molecular dynamics study on a nonequilibrium motion of a colloidal particle driven by an external torque . DONGHWAN YOO, Myongji University, YOUNGKYUN JUNG, KISTI, CHULAN KWON, Myongji University — We investigate the motion of a colloidal particle driven out of equilibrium by an external torque. We use the molecular dynamics simulation that is alternative to the simulation based on the Langevin equation and is expected to mimic an experiment more realistically. We choose a heat bath composed of about a thousand particles interacting to each other through the Lenard-Jones potential and impose the Langevin thermostat to maintain it in equilibrium. We prepare a colloidal particle to interact with the particles of the heat bath also by the Lenard-Jones potential while any dissipative force and noise are not employed explicitly. We study the stochastic properties of the nonequilibrium fluctuation for work and heat produced incessantly in the steady state. We accurately confirm the fluctuation theorem for the work production. We also investigate the motion beyond the overdamped limit by varying the mass of the particle. We compare our result with a previous theoretical result in the overdamped limit based on the Langevin equation[1].


2:03PM M44.00015 Transient Orthogonality Catastrophe in a Time Dependent Nonequilibrium Environment , MARCO SCHIRO, CNRS and CEA-Saclay, ADITI MITRA, NYU, 0 TEAM — We study the response of a highly-excited time dependent quantum many-body state to a sudden local perturbation, a sort of orthogonality catastrophe problem in a transient non-equilibrium environment. To this extent we consider, as key quantity, the overlap between time dependent wave-functions, that we write in terms of a novel two-time correlator generalizing the standard Loschmidt Echo. We discuss its physical meaning, general properties, and its connection with experimentally measurable quantities probed through non-equilibrium Ramsey interferometry schemes. Then we present explicit calculations for a one dimensional interacting Fermi system brought out of equilibrium by a sudden change of the interaction, and perturbed by the switching on of a local static potential. We show that different scattering processes give rise to remarkably different behaviors at long times, quite opposite from the equilibrium situation. In particular, while the forward scattering contribution retains its power law structure even in the presence of a large non-equilibrium perturbation, with an exponent that is strongly affected by the transient nature of the bath, the backscattering term is a source of non-linearity which generates an exponential decay in time of the Loschmidt Echo, reminiscent of

Wednesday, March 4, 2015 2:30PM - 5:30PM – Session Q8 GSNP: Focus Session: Wave Chaos: Theory and Applications 006C - Gabriele Gradoni, University of Nottingham

2:30PM Q8.00001 Caustics Formation and Sharp Focusing in PT-symmetric Waveguide Arrays , NICHOLAS BENDER, Wesleyan University, HAMIDREZA RAMEZANI, NSF Nanoscale Science and Engineering Center, University of California, Berkeley, TSAMPIKOS KOTTOS, Wesleyan University — We investigate focusing effects and curved optical beam trajectories in waveguide arrays consisting of coupled dimers with local Parity-Time symmetry i.e. one element of the dimer has loss and the other an equal amount of gain. When the intra-dimer coupling is stronger than the inter-dimer coupling the propagation constants of this array are real (exact PT-symmetric phase). We find that, under such conditions, appropriate tailoring of the phases and amplitudes of the initial beam can lead to reconfigurable caustic phenomena and curved beam propagation, as well as focusing of the initial beam at paraxial distances controlled by the degree of gain and loss involved in these PT-symmetric structures.

2:42PM Q8.00002 ABSTRACT WITHDRAWN –

2:54PM Q8.00003 Many-Body scattering through mesoscopic chaotic cavities: Universal effects of indistinguishability and interaction . JOSEF MICHL, MARKUS BIBERGIER, Institute of Theoretical Physics - University of Regensburg, JACK KUIPERS, Computational Biology Group - ETH Zurich, JUAN DIEGO URBINA, KLAUS RICHTER, Institute of Theoretical Physics - University of Regensburg — We consider the mesoscopic scattering of identical particles, and study the interplay between three physical effects: universality of single-particle transport, many-body correlations due to quantum indistinguishability, similar to the Hong-Ou-Mandel effect in quantum optics, and the presence of inter particle interactions. Starting from a rigorous construction of the many-body scattering amplitudes, the well-known universality of chaotic wave transport is encoded in the statistical correlations between single-particle scattering matrices and ultimately between classical single-particle paths joining incoming and outgoing channels. For non-interacting systems, very non-trivial combinations of scattering matrices arise due to the symmetrization postulate and a mesoscopic version of the Hong-Ou-Mandel profile is obtained[1]. In a further step, a universal Hamiltonian representing interactions in the base of scattering single-particle states is constructed that allows us to study how inter particle interactions affect the Hong-Ou-Mandel correlations in the regime of mesoscopic chaotic transport. Further studies on the localization of single particles in PT-symmetric chaotic cavities are presented in [2].


3:06PM Q8.00004 Luukko Scars - a New Mechanism for Wavefunction Scar Formation , ERIC HELLER, Harvard University — A new type of scarring phenomenon in bound quantum systems is reported that creates classical orbit localization as a result of localization in classical action. Perturbation of quasi-degenerate manifolds of unperturbed quantum states by a weak random potential is involved. The localization may be related to Anderson localization but this is still under investigation.

4 with Perttu Luukko, Esa Rasansen, Lev Kaplan, Anna Klales, and Byron Drury
4:06PM Q8.00007 Semiclassical propagation of correlation functions in closed electromagnetic environments 1, GABRIELE GRADONI, STEPHEN CREAGH, GREGOR TANNER, University of Nottingham, United Kingdom — Field-field correlation functions can be propagated efficiently within confined systems through the Wigner-Weyl formalism. A semiclassical Frobenius-Perron operator is derived for the propagation of Wigner functions as a solution of the associated boundary integral equation. This idea is used to study the effect of non-integrable (chaotic) dynamics on the propagation of classical noisy fields. Model systems for quantum mechanics are used to mimic the radiation into closed spaces. A realistic model of statistical sources into a semi-open polygonal billiard is also presented. We find that the simplest description in terms of the classical Frobenius-Perron operator provides a description of the frequency-averaged correlation function but that wave-resonant and interference effects can also be accounted for. Applications of the theory focus on the prediction of energy distribution through electromagnetic environments in electromagnetic compatibility, wireless communication systems, and imaging optics.

3Work supported by the UK Engineering and Physical Sciences Research Council

4:18PM Q8.00008 ABSTRACT WITHDRAWN —

4:30PM Q8.00009 Massive simulation of complex electromagnetic cavities 1, FRANCO MOGLIE, LUCA BASTIANELLI, VALTER MARIANI PRIMIANI, Universita Politecnica delle Marche - DII, Ancona — The analysis of the chaotic behavior of complex electromagnetic cavities takes benefit from the availability of a large amount of data on field samples. The application of a code running on a supercomputer is able to return a precise electromagnetic simulation of electrically large structures. The simulations of mode-stirred reverberation chamber (RC) were performed using an in-house parallel finite-difference time-domain (FDTD) code. The code is divided into three modules that are managed by a unique, single-step job: the electromagnetic solver based on the FDTD method; a fast Fourier transform (FFT) to obtain the frequency domain behavior; a statistical tool to obtain the RC properties. A unique run produces statistical results for all the investigated stirrer angles, without the burden of saving intermediate data. The code implements a hybrid parallelization as a function of stirrer angle and cavity volume. Specifically, such a computation is known to be "embarrassingly parallel" with respect to the stirrer angle. The excitation is a Gaussian pulse modulated sinusoid at 1.1 GHz: the 95% bandwidth is 0.2 and 2 GHz. After the FDTD simulation is completed, the FFT module gives the frequency behavior of the fields in each point with a resolution of about 50 kHz.

3We acknowledge PRACE for awarding us access to resource FERMI based in Italy at CINECA

4:42PM Q8.00010 Nonlinear elastic waves in solids: Deriving simplicity from complexity 1, MAHMOUD I. HUSSEIN, ROMIK KHAJEHTOURI, University of Colorado Boulder — The introduction of nonlinearities to the dynamics of a homogeneous elastic medium alters the underlying wave dispersion characteristics. In this work, we present an exact formulation for the treatment of geometric nonlinearity in one-dimensional elastic wave propagation in a rod, considering both a thin rod where the thickness is small compared to the wavelength and a thick rod where lateral inertia is accounted for. Our derivation starts with the implementation of Hamilton’s principle and terminates with an expression for the finite-strain dispersion relation in closed form. We explore the effect of wave amplitude on the derived dispersion relation and compare with results obtained by direct time-domain simulations followed by Fourier transformations. While often dispersion is attributed to only linear mechanisms, here we show that an otherwise linearly nondispersive elastic solid may exhibit dispersion solely due to the presence of a nonlinearity. This work provides insights into the fundamentals of nonlinear wave propagation in solids, which represents one of the agents of wave chaos in complex systems.

4:54PM Q8.00011 Geometry and topology of tangled vortices in wave chaos 1, ALEXANDER TAYLOR, MARK DENNIS, University of Bristol — Linear waves in three-dimensional chaotic systems can contain complex vortex tangles that are difficult to describe analytically, even in non-dynamic systems such as solutions of the time-independent Schrödinger equation in which the vortices are zeros of a complex scalar wavefunction. Despite the linear nature of such eigenfunctions, the local geometry of their vortices leads to random conformations for which certain properties appear universal on large scales, even when compared to vortices in different physical systems such as superfluid turbulence or models of cosmic strings [1]. We numerically track vortex tangle in the random wave model of chaotic eigenfunctions in different systems with the same limiting behaviour at high energy [2]. While many quantities reveal only a common statistical scaling on the large scale, the topology—particularly the occurrence of knotted loops—discriminates between tangles arising from different systems. In fact, knotting seems to depend on the nature of the chaotic system, and can be surprisingly rare when compared to standard random walk models.

5:06PM Q8.00012 Non-Harmonic Pressure Fluctuations by the Self-Excited Oscillations in a Reactor-Column , HASSON M. TAVOSSI, Valdosta State University, Department of Physics, Astronomy, and Geosciences — Self-excited non-harmonic pressure oscillations that result from non-linearity in the system are generated in an air-flow in a reactor column. The uniform steady flow is converted spontaneously into an oscillatory flow, under the especial experimental conditions in a reactor column that includes a thin layer of dissipative porous medium. The resulting large-amplitude non-harmonic pressure fluctuations in the air-flow are similar to the bifurcation in chaotic systems; where two or more energy states can occur simultaneously, with the system oscillating between them. Experimental results will be presented to demonstrate this abrupt change in flow-regime, from steady-flow to chaotic turbulent vibrations. Our results show that a low-pressure shock-wave-front is established in the column and precedes the self-excitation oscillations in the system. Results show that there exists a threshold for flow-rate, beyond which the transition from steady-flow to pulsating-flow occurs. A numerical model is developed to express this behavior in terms of system variables, such as; dominant frequencies, obtained from fast-Fourier-transforms of time-domain pressure signals, flow-rate, dimensionless aerodynamic characteristic numbers, relaxation-time, and energy dissipation in the system.

5:18PM Q8.00013 A spectral force based version of the Wigner-Liouville equation , MAARTEN VAN DE PUT, WIM MAGNUS, BART SORÈE, Univ of Antwerp, imec — Traditionally, a direct numerical solution of the Wigner-Liouville (WL) equation has been plagued with high computational burden and instability inherent to the integration of the highly oscillatory Wigner potential kernel. We have developed a method based on the spectral decomposition of the force which recasts the WL equation into a manageable form. By removing one integral, this new form is computationally less demanding. Furthermore a damping term naturally appears which reduces the instability caused by the oscillatory terms. Finally, the new form is local in position as opposed to the original WL equation which is non-local in both position and momentum. The spectral force WL equation is interpreted as representing two processes; a classical evolution with a constant force, and a local quantum generation term with positive and negative contributions mediated by the spectral components of the force. This interpretation allows for a straightforward implementation using a finite difference scheme for the classical evolution coupled with direct evaluation of the discretized generation terms. We observe a good match between results obtained using our method and theoretical results.

Wednesday, March 4, 2015 2:30PM - 5:18PM —
Session Q44 GSNP: Networks and their applications 214D - Daniëlle Bassett, University of Pennsylvania

2:30PM Q44.00001 Topological Phenotypes in Complex Leaf Venation Networks , HENRIK RONEL-LENFITSCH, JANA LASHER, Max Planck Institute for Dynamics and Self-Organization, DOUGLAS DALY, New York Botanical Garden, ELENI KATIFORI, Max Planck Institute for Dynamics and Self-Organization — The leaves of vascular plants contain highly complex venation networks consisting of recursively nested, hierarchically organized loops. We analyze the topology of the venation of leaves from ca. 200 species belonging to ca. 10 families, defining topological metrics that quantify the hierarchical nestingness and complexity of the two-dimensional phenotypic space, where one dimension consists of a linear combination of geometrical metrics and the other dimension of topological, previously uncharacterized metrics. We show how this new topological dimension in the phenotypic space significantly improves identification of leaves from fragments, by calculating a "leaf fingerprint" from the topology and geometry of the higher order veins. Further, we present a simple model suggesting that the topological phenotypic metrics can be explained by noise effects and variations in the timing of higher order vein developmental events. This work opens the path to (a) new quantitative identification techniques for leaves which go beyond simple geometric traits such as vein density and (b) topological quantification of other planar or almost planar networks such as arterial vasculature in the neocortex and lung tissue.

2:42PM Q44.00002 Nonlinear Dynamics and Control in Microfluidic Networks†, DANIEL CASE, Northwestern University, JEAN-REGIS ANIGLELLA, Université de Caen et de Basse Normandie, ADILSON MOTTER, Northwestern University — Researchers currently use abundant external devices (e.g., pumps and computers) to achieve precise flow dynamics in microfluidic systems. Here, I show our use of network concepts and computational methods to design microfluidic systems that do not depend on external devices yet still exhibit a diverse range of flow dynamics. I present an example of a microfluidic channel described by a nonlinear pressure-flow relation and show that complex flow behavior can emerge in systems designed around this channel. By controlling the pressure at a single terminal in such a system, I demonstrate the ability to switch the direction of fluid flow through intermediate channels not directly connected to the controlled terminal. I also show that adding (or removing) flow channels to a system can result in unexpected changes in the total mass flow rate, depending on the network structure of the system. We expect this work to both expand the applicability of microfluidics and promote scaling up of current experiments.

†This research was funded by the National Science Foundation.

2:54PM Q44.00003 Independence of bond-level response in disordered networks , CARL GOODRICH, ANDREA LIU, University of Pennsylvania, SIDNEY NAGEL, University of Chicago — Many properties of spring networks, such as bulk elasticity, are a sum of contributions from individual bonds. For disordered systems, these contributions are often characterized by continuous distributions with tails that can be many times larger than the average, leading to the appearance of bonds that are "stronger" or "weaker" than others. However, whether a specific bond is strong or weak depends sensitively on the measurement being made; knowing how a bond responds to compression, for example, tells little about how it will respond to shear. This leads to a new principle for disordered solids: independence of bond-level response. We will show how this principle can be exploited to construct metamaterials with unique, textured, tunable and often extreme response.

3:06PM Q44.00004 ABSTRACT WITHDRAWN —

3:18PM Q44.00005 Phase-space network structure of two-dimensional ±J spin glasses†, XIN CAO, Hong Kong Univ of Sci & Tech, FENG WANG, Boston University, YILONG HAN, Hong Kong Univ of Sci & Tech — We illustrate a complex-network approach to study the phase spaces of spin glasses. By exactly mapping the whole ground-state phase spaces of two-dimensional Edwards-Anderson bimodal (±J) spin glasses into networks, we discovered various phase-space properties via network analysis. The Gaussian connectivity distribution of the phase-space networks demonstrates that both the number of free spins and the visiting frequency of microstates follow Gaussian distributions. The spectra of phase-space networks are Gaussian, which is proved to be exact when the system is infinitely large. The phase-space networks exhibit community structures, which enables us to construct the entropy landscape of the ground state as a network and discover its scale-free property. The phase-space networks exhibit fractal structures, as a result of the rugged entropy landscape. Moreover, we show that the connectivity distribution, the community structure and the fractal structure drastically change at the ferromagnetic-glass transition. These quantitative measurements of the ground states provide new insight into the studies of spin glasses. On the other hand, the phase-space networks establish a new class of complex networks with unique topology.

†The work was supported by RGC grants GRF601613.
3:30PM Q44.00006 Thermal Transport in Cayley-Tree Networks1, TSAMPIKOS KOTTOS, HUANAN LI, Wesleyan Univ, BORIS SHAPIRO, Technion — In recent years there has been a lot of attention in the microscopic derivation of the laws that dictate heat current in low dimensional systems. However, many real structures are not simple one or two-dimensional structures. Rather, they are characterized by a complex connectivity that can be easily designed and realized in the laboratory. It is therefore necessary to unveil the rules that dictate thermal transport in such networks. In this contribution we present analytical results on heat current and its thermal fluctuations for a Cayley tree consisting of two types of harmonic masses: vertex masses $N$ where phonon scattering occurs and bond masses $m$ where phonon propagation take place. The tree is coupled to thermal reservoirs consisting of one-dimensional harmonic chain of masses $m$. We find that the heat current is a non-monotonic function of the mass-ratio $\mu = M/m$. In particular, there are cases when the heat current is strictly zero below some critical value $\mu^*$. The effects of imperfections (disorder) on the heat transport are also discussed and analyzed.

3:42PM Q44.00007 Fragmentation of random trees, ZIYA KALAY, Kyoto University, ELI BEN-NAIM, Los Alamos National Laboratory — We investigate the fragmentation of a random recursive tree by repeated removal of nodes, resulting in a forest of disjoint trees. The initial tree is generated by sequentially attaching new nodes to randomly chosen existing nodes until the tree contains $N$ nodes. As nodes are removed, one at a time, the tree dissolves into an ensemble of separate trees, namely a forest. We study the statistical properties of trees and nodes in this heterogeneous forest. In the limit $N \to \infty$, we find that the system is characterized by a single parameter: the fraction of remaining nodes $m$. We obtain analytically the size density $\phi_s$ of trees of size $s$, which has a power-law tail $\phi_s \sim s^{-\alpha}$, with exponent $\alpha = 1 + 1/m$. Therefore, the tail becomes steeper as further nodes are removed, producing an unusual scaling exponent that increases continuously with time. Furthermore, we investigate the fragment size distribution in a growing tree, where nodes are added as well as removed, and find that the distribution for this case is much narrower.

3:54PM Q44.00008 Cascading Failures and Stochastic Analysis for Mitigation in Spatially-Embedded Random Networks1, NOEMI DERZSY, XIN LIN, ALAA MOUSSAWI, BOLESŁAW K. SZYMANSKI, GYORGY KORNIS, Rensselaer Polytechnic Institute — In complex information or infrastructure networks, even small localized disruptions can give rise to congestion, large-scale correlated failures [1], or cascades, – a critical vulnerability of these systems. Recent studies have demonstrated that flow-driven cascading overload failures in spatial graphs, such as the power grid, are non-self-averaging, hence predictability is poor and conventional mitigation strategies are largely ineffective [2]. In particular, we have shown that protecting all nodes (or edges) by the same additional capacity (tolerance) can actually lead to larger global failures, i.e., “paying more can result in less”, in terms of robustness [2]. Here, we explore stochastic methods for optimal heterogeneous distribution of resources (node or edge capacities) subject to a fixed total cost. In addition to random geometric graphs, we also investigate cascading failures on the UCTE European electrical power transmission network. [1] A. Bernstein, D. Bienstock, D. Hay, M. Uzunoglu, and G. Zussman, http://arxiv.org/abs/1206.1099 (2011). [2] A. Asztalos, S. Sreenivasan, B.K. Szymanski, and G. Korniss, PLOS One 9(1): e84563 (2014).

4:06PM Q44.00009 Cooperative SIS epidemics can lead to abrupt outbreaks, FAKHTEH GHANBARNE-JAD, Max Planck Institute for the Physics of Complex Systems, Germany, LI CHEN, Robert Koch-Institute, 13353 Berlin, Germany, WEIRAN CAI, Technische Universität Dresden, Germany, PETER GRASSBERGER, Forschungszentrum Jülich, Germany — In this paper, we study spreading of two cooperative SIS epidemics in mean field approximations and also within an agent based framework. Therefore we investigate dynamics on different topologies like Erdos-Renyi networks and regular lattices. We show that cooperativity of two diseases can lead to strongly first order outbreaks, while the dynamics still might present some scaling laws typical for second order phase transitions. We argue how topological network features might be related to this interesting hybrid behaviors.

4:18PM Q44.00010 Eigenvalue Separation in the Laplacian Spectra of Random Geometric Graphs1, AMY NYBERG, KEVIN E. BASSLER, Department of Physics, University of Houston — The graph Laplacian spectra of networks are important for characterizing both their structural and dynamical properties. As a prototypical example of networks with strong correlations, we investigate the spectra of random geometric graphs (RGGs), which describe networks whose nodes have a random physical location and are connected to other nodes within a threshold distance $r$. RGGs model transportation grids, wireless networks, and biological processes. The spectrum consists of two parts, a discrete part consisting of a collection of integer valued delta function peaks centered about the average degree and a continuous part that exhibits the phenomenon of eigenvalue separation.

4:30PM Q44.00011 Bounds for percolation thresholds on directed and undirected graphs1, KATHLEEN HAMILTON, LEONID PRYADKO, University of California - Riverside — Percolation theory is an efficient approach to problems with strong disorder, e.g., in quantum or classical transport, composite materials, and diluted magnets. Recently, the growing role of big data in scientific and industrial applications has led to a renewed interest in graph theory as a tool for describing complex connections in various kinds of networks: social, biological, technological, etc. In particular, percolation on graphs has been used to describe internet stability, spread of contagious diseases and computer viruses; related models describe market crashes and viral spread in social networks. We consider site-dependent percolation on directed and undirected graphs, and present several exact bounds for location of the percolation transition in terms of the eigenvalues of matrices associated with graphs, including the adjacency matrix and the Hashimoto matrix used to enumerate non-backtracking walks. These bounds correspond to a mean field approximation and become asymptotically exact for graphs with no short cycles. We illustrate this convergence numerically by simulating percolation on several families of graphs with different cycle lengths.


3This work was supported by the NSF through grant PHY-1416578 and by the AFSOR and DARPA through grant FA9550-12-1-0405.

1Supported in part by DTRA, NSF, and ARL NS-CTA.

1This research was supported in part by the NSF grant PHY-1416578 and by the ARO grant W911NF-11-1-0027.
4:42PM Q44.00012 Reconstructing Weighted Networks from Dynamics*, EMILY S.C. CHING, Department of Physics, The Chinese University of Hong Kong, P.Y. LAI, Department of Physics, Graduate Institute of Biophysics, and Center for Complex Systems, National Central University, C.Y. LEUNG, Department of Physics, The Chinese University of Hong Kong — The knowledge of how the different nodes of a network interact or link with one another is crucial for the understanding of the collective behavior and the functionality of the network. We have recently developed a method that can reconstruct both the links and their relative coupling strength of bidirectional weighted networks. Our method requires only measurements of node dynamics as input and is based on a relation between the pseudo-inverse of the matrix of the correlation of the node dynamics and the Laplacian matrix of the weighted network. Using several examples of different dynamics, we demonstrate that our method can accurately reconstruct the connectivity as well as the weights of the links for weighted random and weighted scale-free networks with both linear and nonlinear dynamics.

1The work of ESCC and CYL has been supported by the Hong Kong Research Grants Council under grant no. CUHK 14300914.

4:54PM Q44.00013 Identification of core-periphery structure in networks, XIAO ZHANG, TRAVIS MARTIN, MARK NEWMAN, Univ of Michigan - Ann Arbor — Many networks can be decomposed into a dense core plus an outlying, loosely-connected periphery. In this talk I will describe a method for performing such a decomposition on empirical network data using methods of statistical inference. Our method fits a generative model of core-periphery structure to observed data using a combination of an expectation-maximization algorithm for calculating the parameters of the model and a belief propagation algorithm for calculating the decomposition itself. We find the method to be efficient, scaling easily to networks with a million or more nodes and we test it on a range of networks, including real-world examples as well as computer-generated benchmarks.

5:06PM Q44.00014 Small-World Propensity: A novel statistic to quantify weighted networks, DANIELLE BASSETT, SARAH MULDOON, Univ of Pennsylvania, ERIC BRIDGEFORD, John Hopkins University — Many real-world networks have been shown to display a small-world structure with high local clustering yet short average path length between any two nodes. However, characterization of small-world properties has generally relied on a binarized representation of such graphs, neglecting the important fact that, in reality, many real-world networks are actually composed of weighted connections spanning a wide range of strengths. Here, we present a generalization of the Watts-Strogatz formalism for weighted networks along with a novel statistic called the Small-World Propensity that quantifies both binary and weighted small-world structure. We apply this measure to real-world brain networks and show that by retaining network weights, we are able to better understand the small-world structure of these systems.

Thursday, March 5, 2015 8:00AM - 10:24AM – Session S18 GSNP: Invited Session: Statistical Physics for Electric Grids Mission Room 103A - Guido Caldarelli, IMT Alti Studi Lucca

8:00AM S18.00001 Realistic modeling and analysis of synchronization dynamics in power-grid networks*, TAKASHI NISHIKAWA, Northwestern University — An imperative condition for the functioning of a power-grid network is that its power generators remain synchronized. Disturbances can prompt desynchronization, which is a process that has been involved in large power outages. In this talk I will first give a comparative review of three leading models of synchronization in power-grid networks. Each of these models can be derived from first principles under a common framework and represents a power grid as a complex network of coupled second-order phase oscillators with both forcing and damping terms. Since these models require dynamical parameters that are unavailable in typical power-grid datasets, I will discuss an approach to estimate these parameters. The models will be used to show that if the network structure is not homogeneous, generators with identical parameters need to be treated as non-identical oscillators in general. For one of the models, which describes the dynamics of coupled generators through a network of effective interactions, I will derive a condition under which the desired synchronized state is stable. This condition gives rise to a methodology to specify parameter assignments that can enhance synchronization of any given network, which I will demonstrate for a selection of both test systems and real power grids. These parameter assignments can be realized through very fast control loops, and this may help devise new control schemes that offer an additional layer of protection, thus contributing to the development of smart grids that can recover from failures in real time.

1Funded by ISEN, NSF, and LANL LDRD.

8:36AM S18.00002 Complex Dynamics of the Power Transmission Grid (and other Critical Infrastructures), DAVID NEWMAN, Univ. of Alaska Fairbanks — Our modern societies depend crucially on a web of complex critical infrastructures such as power transmission networks, communication systems, transportation networks and many others. These infrastructure systems display a great number of the characteristic properties of complex systems. Important among these characteristics, they exhibit infrequent large cascading failures that often obey a power law distribution in their probability versus size. This power law behavior suggests that conventional risk analysis does not apply to these systems. It is thought that much of this behavior comes from the dynamical evolution of the system as it ages, is repaired, upgraded, and as the operational rules evolve with human decision making playing an important role in the dynamics. In this talk, infrastructure systems as complex dynamical systems will be introduced and some of their properties explored. The majority of the talk will then focus on the electric power transmission grid though many of the results can be easily applied to other infrastructures. General properties of the grid will be discussed and results from a dynamical complex systems power transmission model will be compared with real world data. Then we will look at a variety of uses of this type of model. As examples, we will discuss the impact of size and network homogeneity on the grid robustness, the change in risk of failure as generation mix (more distributed vs centralized for example) changes, as well as the impact of operational changes such as the changing the operational risk aversion or grid upgrade strategies. One of the important outcomes from this work is the realization that “improvements” in the system components and operational efficiency do not always improve the system robustness, and can in fact greatly increase the risk, when measured as a risk of large failure.

9:12AM S18.00003 Self Healing Percolation*, ANTONIO SCALA, CNR — We introduce the concept of self-healing in the field of complex networks modelling; in particular, self-healing capabilities are implemented through distributed communication protocols that exploit redundant links to recover the connectivity of the system. Self-healing is a crucial in implementing the next generation of smart grids allowing to ensure a high quality of service to the users. We then map our self-healing procedure in a percolation problem and analyse the interplay between redundancies and topology in improving the resilience of networked infrastructures to multiple failures. We find exact results both for planar lattices and for random lattices, hinting the role of duality in the design of resilient networks. Finally, we introduce a cavity method approach to study the recovery of connectivity after damage in self-healing networks.

1CNR-PNR National Project “Crisis-Lab,” EU HOME/2013/CIPS/AG/400005013 project CI2C and EU FET project MULTIPLEX nr.317532
with advanced pulse sequences, we were able to probe the rapid dynamics (voidage and velocity measurements) of gas-solid systems.

severely the temporal resolution of the data acquisition. Here, we report the acquisition of ultra-fast MRI measurements in large volume vessels using medical chemical reactions can be measured. However, so far the investigation of two-phase granular systems has been performed on relatively small-bore systems (max.

ETH Zurich — Several non-intrusive techniques have been applied to probe the dynamics of two-phase granular systems, with the most prominent examples

with the particular advantage that by implementing suitable pulse sequences not only spin densities (i.e. voidage), but also velocity, acceleration, diffusion and

Our X-ray tomography results point to an effective surface tension as the driving mechanism. Additionally, we report on a novel microsegregation phenomenon.

We acknowledge support from the Defense Threat Reduction Agency, BCG and EU FP7 (Growcom).

Thursday, March 5, 2015 8:00AM - 11:00AM

Session S44 GSNP GSOFT: Focus Session: Granular Materials and Continuum Descriptions of Discrete Media 1

8:00AM S44.00001 Giant drag reduction due to interstitial air in sand

DEVARAJ VAN DER MEER, University of Twente, TESS HOMAN, Laboratoire de Physique, ENS Lyon, France — When an object impacts onto a bed of very loose, fine sand, the drag it experiences depends on the ambient pressure in a surprising way. Drag is found to increase significantly with decreasing pressure. We use a modified penetrometer experiment to test at atmospheric conditions. The resulting dependency of both velocity and pressure. We observe a drag reduction of over 90% and trace this effect back to the presence of air in the pores between the sand grains. Finally, we construct a model based on the modification of grain-grain interactions that is in full quantitative agreement with the experiments.

8:12AM S44.00002 Scattering of a legged robot in a heterogeneous granular terrain

FEIFEI QIAN, DANIEL GOLDMAN, Georgia Institute of Technology — Many granular substrates are composed of particles of varying size, from fine sand to pebbles and boulders. Ambulatory locomotion on such heterogeneous substrates is complicated in part due to fluctuations introduced by heterogeneities. To discover principles of movement on such substrates, we developed an automated system, the “Systematic Creation of Arbitrary Terrain and Testing of Exploratory Robots” (SCATTER), to create heterogeneous granular substrates of varying properties such as compaction, inclination, obstacle shape/size/distribution and obstacle mobility within the substrate. We investigate how the presence of a single “boulder” affects the locomotion of a 6-legged robot (15cm, 150g). The robot’s trajectory is straight before boulder interaction, and is scattered to an angle after the interaction. Surprisingly, the interactions with the boulder can lead to both negative and positive scattering angles—an effective attraction and repulsion between the robot and the boulder. The scattering pattern depends sensitively on the leg-boulder contact position and the boulder mobility within the fine sand. However, the scattering pattern dependence upon contact position on the boulder is insensitive to boulder shape (created using 3D printing), orientation and roughness.

This work is funded by DARPA Young Faculty Award and Army Research Laboratory (ARL)

8:24AM S44.00003 Stability of an isolated granular band in a rotating tumbler

PAUL B. UMBANHOWAR, DARIUS WHEELER, JULIO M. OTTINO, RICHARD M. LIEPE TOW, Northwestern University — Granular mixtures tend to segregate into axial bands when tumbling in long, horizontal cylinders. To better understand this phenomenon we experimentally and computationally studied the stability of a single band of large spherical particles initially located between two regions of small spherical particles. Unlike previous work with bidisperse particles, where the band spread axially in a diffusive-like fashion, we found that a single band can stabilize to a constant width much smaller than the cylinder length depending on the size ratio of large to small particles, $R$, and the fill fraction of the tumbler, $f$. Stable bands were observed for $f < 0.3$ and $1.3 < R < 2.3$; for $R >$ outside this interval and $f > 0.3$, bands were unstable and grew diffusively. For $R < 1.3$ large particles diffuse axially in the flowing layer, while for $R > 2.3$ axial motion of large particles occurs mainly at the intersection of the downstream terminus of the flowing layer and the cylinder wall. Lastly, band stability was independent of initial band width for the range we tested (4-40 mm). We discuss possible band stabilization mechanisms in light of these observations.

8:36AM S44.00004 The cause of coarsening

MATTHIAS SCHROETER, MPIDS Goettingen, TILO FINGER, RALF STAN NARIUS, Universitaet Magdeburg — The coarsening process of bands of smaller grains in a horizontally rotated cylindrical drum is a counterintuitive process. Our X-ray tomography results point to an effective surface tension as the driving mechanism. Additionally, we report on a novel microsegregation phenomenon.

8:48AM S44.00005 Analysis of inter-event times for avalanches on a conical bead pile with cohesion

SUSAN LEHMAN, NATHAN JOHNSON, CATHERINE TIEMAN, ELLIOT WAINWRIGHT, Department of Physics, College of Wooster, Wooster, OH — We investigate the critical behavior of a 3D conical bead pile built from uniform 3 mm steel spheres. Beads are added to the pile by dropping them onto the apex one at a time; avalanches are measured through changes in pile mass. We investigate the dynamic response of the pile by recording avalanches from the pile over tens of thousands of bead drops. We have previously shown that the avalanche size distribution follows a power law for beads dropped onto the pile apex from a low drop height. We are now tuning the critical behavior of the system by adding cohesion from a uniform magnetic field and find an increase in both size and number for very large avalanches and decreases in the mid-size avalanches. The resulting bump in the avalanche distribution moves to larger avalanche size as the cohesion in the system is increased. We compare the experimental inter-event time distribution to both the Brownian passage-time and Weibull distributions, and observe a shift from the Weibull to Brownian passage-time as we raise the threshold from measuring time between events of all sizes to time between only the largest system-spanning events. These results are both consistent with those from a mean-field model of slip avalanches in a shear system [Dahmen, Nat Phys 7, 554 (2011)].

9:00AM S44.00006 Ultra-fast parallel magnetic resonance imaging of granular systems

ALEXAN DER PENN, Laboratory for Science and Engineering, ETH Zurich and Institute for Biomedical Engineering, University and ETH Zurich, KLAAS P. PRUESSMANN, Institute for Biomedical Engineering, University and ETH Zurich, CHRISTOPH MÜLLER, Laboratory for Energy Science and Engineering, ETH Zurich — Several non-intrusive techniques have been applied to probe the dynamics of two-phase granular systems, with the most prominent examples being X-ray tomography, positron emission particle tracking (PEPT), electrical capacitance tomography and magnetic resonance imaging (MRI). MRI comes with the particular advantage that by implementing suitable pulse sequences not only spin densities (i.e. voidage), but also velocity, acceleration, diffusion and chemical reactions can be measured. However, so far the investigation of two-phase granular systems has been performed on relatively small-bore systems (max. diameter 60 mm). Such systems are, however, heavily influenced by wall effects. Furthermore, largely only single-coil detection has been employed, limiting severely the temporal resolution of the data acquisition. Here, we report the acquisition of ultra-fast MRI measurements in large volume vessels using medical MRI scanners. Specifically, parallel MRI, i.e. the simultaneous use of multiple receiver coils, has been exploited to speed up the data acquisition. In combination with advanced pulse sequences, we were able to probe the rapid dynamics (voidage and velocity measurements) of gas-solid systems.
9:24AM S44.00008 Simulation of granular flows through their many phases. SACHITH DUNATUNGA, Massachusetts Inst of Tech-MIT — The material point method (MPM) is combined with a constitutive model which allows material to traverse through its many common phases during the flow process. When dense, the material is treated as a pressure sensitive elasto-viscoplastic solid obeying a yield criterion and a plastic flow rule given by the $\mu(I)$ inertial rheology of granular materials. When the free volume exceeds a critical level, the material is deemed to separate and is treated as disconnected, stress-free media. By using the MPM framework, extremely large strains and nonlinear deformations such as those common to granular flows can be represented. The method has been shown to replicate results such as Beveloo scaling in silo discharge, as well as the Bagnold profile on an inclined plane.

9:36AM S44.00009 Modeling granular inclined plane flow phenomena with Nonlocal Granular Fluidity. KEN KAMRIN, MIT, DAVID HENANN, Brown University — The continuum theory of Nonlocal Granular Fluidity (NGF) has previously been shown to predict steady granular flow fields in many different geometries, including those such as split-bottom cells, which have been historically resistant to continuum modeling. Central to NGF is a direct inclusion of a particle length-scale, which renders the rheology nonlocal, capturing the cooperatively of granular motion. In this talk we demonstrate that the same model also captures the behaviors observed in granular inclined plane flows. We show that the model predicts a quantitatively accurate "stopping curve" which indicates the conditions that determine when a flowing layer comes to a stop, which depends explicitly on the thickness of the layer. We also explore other known phenomena in this geometry, such as the dependence of the flow profile on layer thickness, the collapse of the Froude number as a function of thickness vs the stopping height, and the possibility of modeling both starting and stopping curves within the same model.

9:48AM S44.00010 Flow Profiles and Fluctuations Measured for Granular Flow in a Vertical Channel, DONALD CANDELA, KEVIN FACTO, Univ of Mass - Amherst — The average velocity profiles and the velocity fluctuations were measured for flows of a dense granular medium (corn poppy seeds) through a long vertical channel, using NMR. The flow profiles seem to be in good agreement with non-local constitutive laws that have been proposed. In particular, there is a shear band near the channel wall with width that is independent of the flow rate. However, the measured velocity fluctuations do not agree with expectations from a simple interpretation of the underpinnings of the non-local rheology. For example, there are large fluctuations in the velocity of the central portion of the flow, away from the walls. This apparent discrepancy may be due to the absence of constant-pressure boundary conditions in granular flow through a fixed-size channel.

1Supported by NSF Grant CBET-0651397

10:00AM S44.00011 High speed impacts on a granular material1, YUE ZHANG, Duke University, ABRAHAM CLARK, Yale University, LOU KONDIC, NJIT, BOB BEHRINGER, Duke University — When an object strikes a granular material, its momentum and energy are transferred to the grains and dissipated. When the ratio of the intruder speed, $v_o$, to a typical granular sound speed, $c$, is small, this energy transfer is intermittent along force-chain-like structures, leading to an inertial drag term proportional to the square of the intruder speed. However, many natural and industrial examples of granular impact occur much closer to $M' \equiv v_0/c \sim 1$, a regime which is difficult to reach in a lab setting using many common granular materials. We address this problem, perform experiments (and matching simulations) with granular materials comprised of photoelastic disks of varying stiffness (and thus, varying $c$), in order to probe regimes closer to $M' \sim 1$. As $M'$ increases, the inertial drag law fails and the material begins to behave more elastically, with a shock-like front propagating away at impact. This causes the penetration depth to be greatly reduced, and in extreme cases, the intruder can rebound temporarily. We understand this transition to damped, elastic-like behavior by comparing the grain-grain collision time to the time for the intruder to move one grain diameter.

1Supported by DTRA grant HDTRA1-10-1-0021, NASA grant NNX10AU01G, and NSF grant DMR1206351

10:12AM S44.00012 Avalanches, and evolution of stress and fabric for a cyclically sheared granular material1. DENGMING WANG, Lanzhou University, JONATHAN BARES, DONG WANG, BOB BEHRINGER, Duke University — Granular materials yield for large enough shear stress, leading to avalanches. We seek to understand the relation between macroscopic avalanches and the microscopic granular structure. We present an experimental study of a 2D granular material subjected to cyclic pure shear, which we visualized by a photo-elastic technique. We start from a stress-free sample of frictional particles in the shear-jamming regime ($\phi_s \leq \phi \leq \phi_j$). We apply multiple cycles of pure shear: shear in one direction, followed by a reversal to the original boundary configuration. The strain is made in small quasi-static steps: after each small step, we obtain polarized and unpolarized images yielding particle-scale forces and locations. Statistical measures of the avalanches are in reasonable agreement with recent mean-field avalanche models by Dahmen et al. (Nature Physics 7, 554 (2011)) The system structure evolves slowly to reduce the stress at the extremum of strain, similar to the relaxation observed by Ren et al. (Phys. Rev. Lett. 110, 018302 (2013)) in a simple shear experiment. To understand how this relaxation occurs, we track the stress and fabric tensors and measures of the strain field over many cycles of shear.

1Supported by NASA grant NNX10AU01G, and NSF grants DMR1206351 and DMS1248071

10:24AM S44.00013 Statistics from granular stick-slip experiment1. AGHIL ABED ZADEH, JONATHAN BARES, ROBERT BEHRINGER, Duke Univ — We carry out experiments to characterize stick-slip for granular materials. In our experiment, a constant speed stage pulls a slider which rests on a vertical bed of circular photoelastic particles in a 2D system. The stage is connected to the slider by a spring. We measure the force on the spring as well as the slider’s acceleration by a force sensor attached to the spring and accelerometers on the slider. The distributions of energy release and time duration of avalanches during slip obey power laws. We apply a novel event recognition approach using wavelets to extract the avalanche properties. We compare statistics from the wavelet approach with those obtained by typical methods, to show how noise can change the distribution of events. We analyze the power spectrum of various quantities to understand the effect of the loading speed of the spring stiffness on the statistical behavior of the system. Finally, from a more local point of view and by using a high speed camera and the photoelastic properties of our particles, we characterize the internal granular structure during avalanches.

1This work is supported by NSF Grant DMR1206351 and NASA grant NNX10AU01G
Granular dynamics under shear with deformable boundaries, Drew Geller, Scott Backhaus, Robert Ecke, Los Alamos National Laboratory — Granular materials under shear develop complex patterns of stress as the result of granular positional rearrangements under an applied load. We consider the simple planar shear of a quasi two-dimensional granular material consisting of bi-dispersed nylon cylinders confined between deformable boundaries. The aspect ratio of the gap width to total system length is 50, and the ratio of particle diameter to gap width is about 10. This system, designed to model a long earthquake fault with long range elastic coupling through the plates, is an interesting model system for understanding effective granular friction because it essentially self tunes to the jamming condition owing to the hardness of the grains relative to that of the boundary material, a ratio of more than 1000 in elastic moduli. We measure the differential strain displacements of the plates, the inhomogeneous stress distribution in the plates, the positions and angular orientations of the individual grains, and the shear force, all as functions of the applied normal stress. There is significant stick-slip motion in this system that we quantify through our quantitative measurements of both the boundary and the grain motion, resulting in a good characterization of this sheared 2D hard sphere system.

Thursday, March 5, 2015 11:15AM - 1:39PM – Session T3 FPS GSNP: Invited Session: Network and Grid Resilience 002AB - Micah Lowenthal, National Academy of Science

11:15AM T3.00001 Electric Distribution Grid Resilience R&D by the U.S. DOE, Dan Ton, U.S. Department of Energy — The U.S. Department of Energy’s Smart Grid Research and Development Program is undertaking R&D to modernize the distribution portion of the electricity delivery system. Key characteristics of a modernized electric distribution grid include reliability, efficiency, affordability, flexibility, and resilience of electricity delivery for all end uses. To address resilience, the Program has established a focused R&D area in FY15 aiming to reduce social consequences (economic, safety, and security) from extreme weather threats. This focus area was developed as the result of an established process in which the Program engaged national labs, universities, utilities, and other industry stakeholders to jointly envision the future state of a resilient grid, to identify R&D areas and activities of priority, and to define performance metrics and associated targets. This presentation will cover the development of the electric distribution grid R&D focus area to date, including its key elements in resilience metrics, enhanced system designs, improved preparedness and mitigation measures, and improved system response and recovery. Key findings from a stakeholder workshop and the year-one Quadrennial Energy Review (QER) report by federal agencies will be summarized. Further, examples of ongoing projects in this focus area supported by the Program will be featured. The presentation will conclude with highlighting some key activities planned by the Program for the near future.

11:51AM T3.00002 Designing Resilient Electrical Distribution Grids—R&D Challenges, Scott Backhaus, Los Alamos National Laboratory — Natural disaster such earthquakes, hurricanes, and other extreme weather pose serious risks to modern critical infrastructure including electrical distribution grids, as evidenced by recent events like Superstorm Sandy. To improve resilience to these events, recent U.S. government studies suggest that component and system-level hardening and resilience upgrades are needed, including adding redundant circuit segments, hardening transformers and other exposed components, adding switching and microgrid generation for flexibility. All of these upgrades are expensive. New methods are needed to design cost-efficient, high-performance combinations of upgrades. A network-centric resilience design approach is described and used to highlight several areas in need of fundamental research to improve the functionality of this and related resilience design tools.

12:27PM T3.00003 Resiliency of Distribution Systems: State-of-the-Art and the Future, Chen-Ching Liu, Washington State University — Recent development of the smart grid significantly enhanced the level of automation in the distribution grids. With a higher level deployment of remote-controlled switches, distribution feeders can be restored more efficiently after power outages. In this presentation, computational algorithms for feeder restoration will be summarized together with their practical implementations. The traditional analytical techniques, however, are not designed for extreme events in the distribution systems. The same is true for widely adopted reliability indices. New thinking of design and operation for resilient distribution systems will be presented, including the development of the state of the art. The presentation will also discuss the future direction of research for resilient distribution systems.

1:03PM T3.00004 Resilience of Large-Scale Power Distribution: Modeling and Real Data, Chuanyi Ji, ECE, Georgia Tech — Severe weather events are extreme but realistic scenarios of large-scale disruptions to power distribution, the last mile of our energy infrastructure. The impact of severe weather is significant: Each major disruption previously occurred caused power failures to millions of customers in large geographical areas for extended durations. A resilient power grid is called for in the nation, which poses a numerous fundamental questions. For example, how to quantify the resilience? How resilient is large-scale power distribution to severe weather? In this talk, we first discuss technical challenges for quantifying resilience that involve heterogeneous factors from power distribution to services. We then show that these factors can be modeled, in a network setting, through spatial-temporal random processes. A dynamic resilience metric is then derived from the model. The model and the metric guide us to learn resilience from real data. We will present a study, using large-scale real data on failures and recoveries, to understand how resilient power distribution is to a severe-weather disruption. Joint work with Yun Wei and Henry Mei (Georgia Tech), in collaboration with utilities and policy makers, and supported by NYSERDA.


11:15AM T44.00001 ABSTRACT WITHDRAWN

11:27AM T44.00002 ABSTRACT WITHDRAWN
11:39AM T44.00003 Shear of ordinary and elongated granular mixtures\textsuperscript{1}  

ALEXANDER HENSLEY, MATTHEW KERN, Rochester Institute of Technology — We present an experimental and computational study of a mixture of discs and moderate aspect-ratio ellipses under two-dimensional annular planar Couette shear. Experimental particles are cut from acrylic sheet, are essentially incompressible, and constrained in the thin gap between two concentric cylinders. The annular radius of curvature is much larger than the particles, and so the experiment is quasi-2D and allows for arbitrarily large pure-shear strains. Synchronized video cameras and software identify all particles and track them as they move from the field of view of one camera to another. We are particularly interested in the global and local properties as the mixture ratio of discs to ellipses varies. Global quantities include average shear rate and distribution of particle species as functions of height, while locally we investigate the orientation of the ellipses and non-affine events that can be characterized as shear transformational zones or possess a quadrupole signature observed previously in systems of purely circular particles. Discrete Element Method simulations on mixtures of circles and spherocylinders extend the study to the dynamics of the force network and energy dissipated as the system evolves.\textsuperscript{1}

\textsuperscript{1}Supported by NSF CBET \#1243571 and PRF \#54138-UR10.

11:51AM T44.00004 Maxwell Construction for a Nonequilibrium Steady-State Phase Separation in Granular Matter  

MARCO G. MAZZA, JAMES CLEWETT, Max Planck Institute for Dynamics and Self-Organization, JACK WADE, ROGER BOWLEY, University of Nottingham, STEPHAN HERMINGHAUS, Max Planck Institute for Dynamics and Self-Organization, MICHAEL SWIFT, University of Nottingham — Experiments and computer simulations are carried out to investigate phase separation in a granular gas under external vibration in a large sample cell. The densities of the dilute and the dense phase are found to follow a lever rule, suggesting an equation of state. We show that this equation of state, which exhibits a non-monotonic pressure-volume character, \( P(v) \), can be obtained from simulations of a small cell. A Maxwell construction is found to predict both the coexisting pressure and binodal densities remarkably well, despite the fact that \( P(v) \) is not an isothermal. Although the system is far from equilibrium and energy conservation is strongly violated, we can derive this finding from an energy minimization argument of uniting currents.

12:03PM T44.00005 Electrical charging in shaken granular media\textsuperscript{1}  

FREJA NORDSIEK, DANIEL LATHROP, University of Maryland College Park — Collisional electrification of granular particles and the resulting electric fields are seen but poorly understood in sand storms, volcanic ash clouds, thunderstorms, and thundersnow. We present results on the electrical charging of granular media (100 micron to 1 mm in size) shaken between two conducting plates. The voltage between the plates was measured. We saw particle electrification through capacitive coupling with the plates and electrical discharges for a diverse class of materials: polystyrene (polymer), soda-lime glass (glass), 69\%:31\% ZrO\textsubscript{2}:SiO\textsubscript{2} (ceramic), and aluminum (metal). We found 1) a monotonic increase in charging with shaking strength, 2) a threshold in the number of particles to see charging of about the number of particles needed to form a monolayer on the plate, 3) material and diameter differences causing an order of magnitude spread in measured signal but little difference between mono-material sets with one size range and bi-material and/or bi-size range set combinations, and 4) long time scale transients. We argue that while two-body collisions and the physical properties of the particles (material and size) are relevant, collective phenomena are a necessary part of explaining natural charging of granular flows.\textsuperscript{1}

\textsuperscript{1}We gratefully acknowledge funding from the Julien Schwinger Foundation.

12:15PM T44.00006 Complex Kepler Orbits and Particle Aggregation in Charged Microscopic Grains  

VICTOR LEE, Univ of Chicago, SCOTT WAITUKAITIS, Leiden University, MARC MISKIN, Cornell University, HEINRICH JAEGER, Univ of Chicago — Kepler orbits are usually associated with the motion of astronomical objects such as planets or comets. Here we observe such orbits at the microscale in a system of charged, insulating grains. By letting the grains fall freely under vacuum, we eliminate the effects of air drag and gravity, and by imaging them with a co-falling high-speed camera we track the relative positions of individual particles with high spatial and temporal precision. This makes it possible to investigate the behaviors caused by the combination of long-range electrostatic interactions and short-range, dissipative, contact interactions in unprecedented detail. We make the first direct observations of microscopic elliptical and hyperbolic Kepler orbits, collide-and-capture events between pairs of charged grains, and particle-by-particle aggregation into larger clusters. Our findings provide experimental evidence for electrostatic mechanisms that have been suspected, but not previously observed at the single-event level, as driving the early stages of particle aggregation in systems ranging from fluidized particle bed reactors to interstellar protoplanetary disks. Furthermore, since particles of different net charge and size are seen to aggregate into characteristic spatial configurations, our results suggest new possibilities for the formation of charge-stabilized “granular molecules”. We can reproduce the observed molecule configurations by taking-body, dielectric polarization effects into account.

12:27PM T44.00007 A nonlinear feedback model for granular and surface charging\textsuperscript{1}  

TROY SHIN-BROT, LEO KOZACHKOV, THEO SIU, Rutgers University — Independent laboratories have experimentally demonstrated that identical materials brought into symmetric contact generate contact charges. Even the most basic features of this odd behavior remain to be explained. In this talk, we provide a simple, Ising-like, model that appears to account for many of the observed phenomena. We calculate the electric field acting on surface molecules in a lattice, and we show that if the molecules are polarizable, then infinitesimal random polarizations typically build exponentially rapidly in time. These polarizations self-assemble to produce surface patterns that come in two types, and we find that one of these types accounts for strong localized charging, while the other produces a weaker persistent surface charge pattern. We summarize predictions for both ideal surfaces and for defects in granular beds.\textsuperscript{1}

\textsuperscript{1}This work was supported by NSF grant DMR-140792.

12:39PM T44.00008 Normal and Tangential Coefficient of Restitution Measurements in an Inelastic Billiard Experiment  

JEFFREY OLAFSEN, MARTIN MARTINEZ, Physics Department, Baylor University — Driven granular media generate a large amount of dissipation in their particle-particle and particle-boundary interactions. As such, our understanding of the fundamental dynamics in these systems is complicated by the velocity-dependent nature of the coefficient of restitution of these interactions. Indeed, how a driven granular flow jams also necessitates a better understanding of the details of this dissipative mechanism. A large number of very sophisticated experiments have sought to better understand and predict the velocity dependence of the coefficient of restitution by trying to constrain and control aspects of the particle-particle or particle-boundary collisions. Here, a careful and in-depth analysis from previously published results \cite{1} for an inelastic billiard moving within a confining boundary allows the velocity-dependence to be measured as the dynamics freely evolve over multiple collisions in the driven system. The large amount of data generated in this experiment allows the contributions from both the normal and tangential velocity components in the particle-boundary interactions to be examined. Two derivative experiments, one for particle-boundary and the other for particle-particle collisions will also be discussed.

shows that the way we introduce a fluid into a granular medium affects the formation of water channels. Results permit us to calculate the ideal flow rate for
Using controlled experiments in a quasi-2D cell and varying physical parameters (particle size, fluid viscosity, etc.), we simulate rainfall and characterize the
PA 19014 — We investigate the physical mechanisms that govern the formation of water channels that develop from finger instabilities at the wetting front.
la Mati`ere Molle (SIMM), ESPCI, Paris, France 75005, DOUGLAS DURIAN, Department of Physics and Astronomy, University of Pennsylvania, Philadelphia,
Department of Physics and Astronomy, University of Pennsylvania, Philadelphia, PA 19014, CHRISTIAN FRETIGNY, CNRS UMR 7615 Sciences et Ing´enierie de
strikes. Inspired by this similarity, we monitor the morphology of resulting impact craters. Surprisingly, we find that, despite the enormous energy and length difference, granular impact cratering varying in size alone, is proportional to the square root of gravity which is often assumed but was never validated. To be more precise concerning the effects of varying gravity on the steady states of bidisperse flows, varying in size alone, we investigate how the Peclet number (ratio of the segregation rate to diffusion)
1:15PM T44.00011 Formation and properties of a dynamic suspension — TESSIONOMAN, VAL´ERIE VIDAL, SYLVAIN JOUBAUD, Laboratoire de Physique, Ecole Normale Sup´erieure de Lyon — We experimentally study the behaviour of an immersed granular bed in a Hele-Shaw cell when perturbed by an airflow from a single inlet at the bottom. When the particles are slightly heavier than the liquid, the competition between particles being dragged up into the liquid and particles settling due to gravity results in a dynamic suspension. In the stationary regime, part of the initial granular bed never moves, and forms a so-called “dead zone.” We investigate its shape and extent as a function of the parameters (air flow-rate, initial grain and liquid height). We also follow the dynamics of the suspension by focussing on the latitude field in the Hele-Shaw cell. The mean density and density fluctuations of the suspension are studied as a function of the gas flow-rate and the ratio between the amount of grains and liquid.
1:27PM T44.00012 Raindrop impact on sand: dynamic and crater formation — SONG-CHUAN ZHAO, RIANNE DE JONG, DEVARAJ VAN DER MEER, Univ of Twente — Droplet impact on a granular bed is very common in nature, industry, and agriculture and extends from raindrops falling on earth to wet granulation in the production process of many pharmaceuticals. In contrast to more traditionally studied impact phenomena, such as a droplet impact on solid substrate and solid object impact on fluid-like substrate, raindrop impact on sand induces more complicated interactions. First, both the intruder and the target deform during impact; second, the liquid composing the droplet may penetrate into the substrate during the impact and may, in the end, completely merge with the grains. These complex interactions between the droplet intruder and the granular target create the very diverse crater morphologies that has been described in the literature. An appealing and natural question is how the craters are formed. To gain insight in the mechanism of crater formation, we resolve the dynamics with high-speed laser profilometry and study the dependence of the dynamics on impact speed and packing fraction of the granular substrate. Finally, we establish a dynamical model to explain the various crater morphologies.
1:39PM T44.00013 Granular impact cratering by liquid drops: Understanding raindrop imprints through an analogy to asteroid strikes — XIANG CHENG, RUNCHEN ZHAO, QIANYUN ZHANG, HENDRO TJUGITO, University of Minnesota — When a granular material is impacted by a sphere, its surface deforms like a liquid yet it preserves a circular crater like a solid. Although the mechanism of granular impact cratering by solid spheres is well explored, our knowledge on granular impact cratering by liquid drops is still very limited. Here, by combining high-speed photography with high-precision laser profilometry, we investigate liquid-drop impact dynamics on granular surface and monitor the morphology of resulting impact craters. Surprisingly, we find that, despite the enormous energy and length difference, granular impact cratering by liquid drops follows the same energy scaling and reproduces the same crater morphology as that of asteroid impact craters. Inspired by this similarity, we integrate the physical insight from planetary sciences, the liquid marble model from fluid mechanics and the concept of jamming transition from granular physics into a simple theoretical framework that quantitatively describes all the main features of liquid-drop imprints in granular media. Our study sheds light on the mechanisms governing raindrop impacts on granular surfaces and reveals a remarkable analogy between familiar phenomena of raining and catastrophic asteroid strikes.
1:51PM T44.00014 Kinetics of Gravity-Driven Water Channels under Steady Rain — REMI DREYFUS, CESARE CEJAS, REMI BARROIS, CNRS-Solvay-Upenn UM3254, Complex Assemblies of Soft Matter, COMPASS, Bristol; PA, USA 19007, YULI WEI, Department of Physics and Astronomy, University of Pennsylvania, Philadelphia, PA 19014, CHRISTIAN FREITIGNY, CNRS UMR 7615 Sciences et Ing´enierie de la Mati`ere Molle (SIMM), ESPCI, Paris, France 75050, DOUGLAS DURIAN, Department of Physics and Astronomy, University of Pennsylvania, Philadelphia, PA 19014 — We investigate the physical mechanisms that govern the formation of water channels that develop from finger instabilities at the wetting front. Using controlled experiments in a quasi-2D cell and varying physical parameters (particle size, fluid viscosity, etc.), we simulate rainfall and characterize the homogeneous wetting front as well as channel size and estimate relevant time scales associated with the instability as well as channel velocity. We validate the results by developing a model based on linear-stability analyses with the addition of another term describing the homogenization of the wetting front. This shows that the way we introduce a fluid into a granular medium affects the formation of water channels. Results permit us to calculate the ideal flow rate for maximizing water distribution and minimizing runoffs using granular and fluid properties.
2:03PM T44.00015 Splash Suppression by Solvent Viscosity in Dense Suspension Impact — WENDY ZHANG, KEVIN DODGE, IVO PETERS, MARTIN KLEIN SCHAARSBERG1, HEINRICH JAEGGER, University of Chicago — When a dense suspension droplet impacts a hard surface, it will either break apart (“splash”) or remain in a compact configuration without ejecting any particles. We use experiments and discrete particle simulations in which relative particle motions are penalized by lubrication-flow drag to analyze the influence of solvent viscosity on splashing. We find that suspension splash is driven by particle inertia. It can be suppressed in 2 different ways. At low solvent viscosity, lubrication drag due to viscous flow has a negligible effect. Splash is suppressed by surface tension overcoming particle inertia. At high solvent viscosity, lubrication drag alone suppresses splashing. Because impact produces an expanding flow that stretches the suspension radially, suppression in the high-viscosity regime is largely accomplished by lubrication-flow drag preventing initially nearby particle pairs from separating fully. Energy dissipation by viscous flow during collisions plays a smaller role. 1Present Address: Physics of Fluids Group, University of Twente
The data as interpreted through this model suggest that the fraction of individual grain microstates that can lead to a clog is constant for large opening sizes. Independent of the aperture shape, size, and orientation. We find for circular holes that this behavior is not universal. For example, monodisperse frictionless systems that crystallize under compression, show very different scaling properties compared to other systems, particularly as the systems approach jamming transition. The findings are confirmed by explicitly computing fractal dimension of the considered clusters.

Supported by the NSF Grant No. DMS-083561

Work supported by NSF grants CBET-1133126 and CBET-1435861 and by NSF award PHY-1156339. Computations carried out at the CIRC at the University of Rochester.

The clogging of granular media flowing from a hopper is a quintessential example of a system that spontaneously evolves from a freely flowing state to a jammed state under constant forcing. If suitably arranged, the grains at the opening are stable, initiate a jamming front, and block the flow throughout the bulk. We measure the fraction \( F \) of possible grain arrangements that lead to such a system-spanning clog for a range of experimental conditions, varying aperture shape, size, and orientation. We find for circular holes that \( F \) is a function only of the aperture size \( a \) and unique composition \( f_s \). In binary spheres, maximally dense, random packing is achieved at infinite size ratio and unique composition \( f_s = 0.2659 \) where small spheres jam within interstitial volume of jammed large spheres, leading to a kink in total volume fraction, \( \phi \), vs. \( f_s \). Using simulations of athermally jammed packings, we explore how this critical feature influences the evolution of random binary sphere packings at finite size ratio, \( \alpha \), ranging from 1 to 10. We report a clear distinction between large and small \( \alpha \) behavior, separated by a critical value of \( \alpha_c \approx 5.8 \). For \( \alpha < \alpha_c \), structural properties--such as total volume fraction, rattler fraction and contact statistics--are found to crossover smoothly from small to large \( f_s \), while above a critical size asymmetry these properties indicate an abrupt, first-order like transition. We correlate this sharp transition with a “sub-jamming” transition of small-spheres occurring at finite values of \( f_s \), which becomes cooperative only for sufficiently asymmetric mixtures. We propose a heuristic geometric and mechanical argument to understand what determines \( \alpha_c \).

We experimentally apply a cyclic pure shear deformation to a two-dimensional foam at different densities. By suspending slightly polydisperse, soft photoelastic gel spheres in an index-matching fluid, we obtain a direct method to assess spatial stress fields in the bulk. Using a rheometer equipped with a camera and simple optics, we simultaneously probe the rheology and force structures in Couette geometry. Our experimental system gives insight in the anisotropy of force structures inside flowing suspensions, one of the mechanisms behind the emergent shear-induced rigidity in these materials.

We probe the onset of irreversibility and relate this to local rearrangements in the system and show the behavior close to jamming is different from that in dense systems.

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4:18PM W44.00008 Effect of Friction on Shear Jamming1

DONG WANG, Duke University, JIE REN, Merck & Co., JOSHUA DIJKSMAN, Wageningen University and Research Centre, JONATHAN BARES, ROBERT BEHRINGER, Duke University — Shear jamming of granular materials was first found for systems of frictional disks, with a static friction coefficient \( \mu \approx 0.6 \) (Bi et al. Nature (2011)). Jamming by shear is obtained by starting from a zero-stress state with a packing fraction \( \phi \) between \( \phi_1 \) (isotropic jamming) and a lowest \( \phi_2 \) for shear jamming. This phenomenon is associated with strong anisotropy in stress and the contact network in the form of force chains, which are stabilized and/or enhanced by the presence of friction. Whether shear jamming occurs for frictionless particles is under debate. The issue we address experimentally is how reducing friction affects shear jamming. We present the Teflon-wrapped photoelastic disks, lowering the friction substantially from previous experiments, in a well-studied 2D shear apparatus (Ren et al. PRL (2013)), which provides a uniform simple shear. Shear jamming is still observed; however, the difference \( \phi_1 - \phi_2 \) is smaller with lower friction. We also observe larger anisotropies in fragile states compared to experiments with higher friction particles at the same density. In ongoing work we are studying systems using photoelastic disks with fine gears on the edge to generate very large effective friction.

1We acknowledge support from NSF Grant DMR1206351, NSF Grant DMS-1248071, NASA Grant NNX10AU01G and William M. Keck Foundation.

4:30PM W44.00009 Clogging and Jamming Transitions in Granular Matter Flowing Through Obstacles

CYNTHIA OLSON REICHHARDT, CHARLES REICHHARDT, Los Alamos National Laboratory — We consider a two-dimensional system of bidisperse disks driven through a landscape of fixed obstacles. In the limit of a single obstacle, the disks cease moving when the disk density is increased to the jamming density. The threshold density value decreases as the number of obstacle increases, but we also observe a change in the nature of the frozen state. At low obstacle density we find a homogenous jammed state, but for higher obstacle density we instead find a heterogeneous clogged state containing void areas and possessing a memory of the driving direction. The transition to the clogged state is strongly stochastic and we observe large fluctuations in clogging time both for clogging in the original driving direction and for transverse clogging when the drive is suddenly rotated by 90 degrees. We find evidence for a diverging clogging transition time at a critical disk density well below the jamming density in a clean system.

4:42PM W44.00010 Diffusion in jammed particle packs

DAN S. BOLINTINEANU, Sandia National Laboratories, LEONARDO E. SILBERT, University of Southern Illinois, GARY S. GREST, JEREMY B. LECHMAN, Sandia National Laboratories — Diffusive transport in jammed particle packs is of interest for a number of applications, as well as being a potential indicator of structural properties near the jamming point. To this end, we report stochastic simulations of equilibrium diffusion through monodisperse sphere packs near the jamming point in the limit of a perfectly insulating surrounding medium. The time dependence of various diffusion properties is resolved over several orders of magnitude. Two time regimes of expected Fickian diffusion are observed, separated by an intermediate regime of anomalous diffusion. This intermediate regime grows as the particle volume fraction approaches the critical jamming transition. The diffusion behavior is fully controlled by the extent of the contacts between neighboring particles, which in turn depend on proximity to the jamming point. In particular, the mean first passage time associated with the escape of random walkers between neighboring particles is shown to control both the time to recover Fickian diffusion and the long time diffusivity. Scaling laws are established that relate these quantities to the difference between the actual and critical jamming volume fractions.

3Sandia National Laboratories is a multiprogram laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy’s NNSA under Contract DE-AC04-94AL85000.

4:54PM W44.00011 Statistics and Correlations of Conserved Quantities in Mechanically Stable Packings of Frictionless Disks Above Jamming

STEPHEN TEITEL, YEYANG WU, Univ of Rochester — We consider mechanically stable packings of soft-core, frictionless, bidisperse disks in two dimensions above the jamming transition. Using an algorithm that generates packings with an isotropic global stress tensor, we compute the distribution of various conserved quantities on compact subclusters of particles, as a function of the total system stress and the cluster size. We consider the stress on the cluster, the Maxwell-Cremona force-tile area, the Voronoi volume, and the numbers of small and big particles in the cluster, and we compute the averages, variances and correlations among these different quantities. We compare two different ensembles of clusters: (i) clusters defined by a fixed radius, and (ii) clusters defined by a fixed number of particles. We find several significant differences between these two ensembles and we comment on the implications of our findings for maximum entropy models of jammed packings.

1This work was supported by NSF Grant No. DMR-1205800. Computations were carried out at the Center for Integrated Research Computing at the University of Rochester.

5:06PM W44.00012 Shear Jamming in Frictionless Particulate Media1

THIBAULT BERTRAND, COREY S. O’HERN, Yale University, R.P. BEHRINGER, Duke University, BULBUL CHAKRABORTY, Brandeis University, MARK D. SHATTUCK, City College of the City University of New York — We numerically study two-dimensional packings of frictionless bidisperse disks created using compressive and simple shearing protocols. To create jammed packings by compression, we start \( N \) particles from random positions and grow their diameters followed by relaxation of particle overlaps using energy minimization. These compressed packings exist over a range of packing fractions \( \phi \). As a result, during compression the system may reach a \( \phi \) above the minimum value before jamming. If this unjammed packing is then sheared by a strain \( \gamma \), it can jam. Using a combination of compression and shearing, we can define jamming protocols as trajectories in the \((\phi, \gamma)\) plane that yield jammed packings. In this plane, we can reach a particular point \((\phi_1, \gamma_1)\) in many ways. We will focus on two protocols: (1) shearing to \( \gamma_1 \) at \( \phi = 0 \) followed by compression to \( \phi_1 \) at \( \gamma = \gamma_{\text{final}} \), and (2) compression to \( \phi_1 \) at \( \gamma = 0 \) followed by shearing to \( \gamma_0 \) at \( \phi = \phi_1 \). For protocol 1, we find that the probability of finding a jammed packing at \( \phi \) and \( \gamma \), \( P(\phi, \gamma) = Q(\phi) \) is independent of \( \gamma \). For protocol 2, we use a simple theory to deduce \( P(\phi, \gamma) \) from \( Q(\phi) \).

1W. M. Keck Foundation Science and Engineering Grant

5:18PM W44.00013 Jammed elastic shells - a 3D experimental soft frictionless granular system

JISSY JOSE, GERHARD A. BLAB, ALFONS VAN BLAADEREN, ARNOUT IMHOF, Utrecht University — We present a new experimental system of monodisperse, soft, frictionless, fluorescent labelled elastic shells for the characterization of structure, universal scaling laws and force networks in 3D jammed matter. The interesting fact about these elastic shells is that they can reversibly deform and therefore serve as sensors of local stress in jammed matter. Similar to other soft particles, like emulsion droplets and bubbles in foam, the shells can be packed to volume fractions close to unity, which allows us to characterize the contact force distribution and universal scaling laws as a function of volume fraction, and to compare them with theoretical predictions and numerical simulations. However, our shells, unlike other soft particles, deform rather differently at large stresses. They deform without conserving their inner volume, by forming dimples at contact regions. At each contact one of the shells buckled with a dimple and the other remained spherical, closely resembling overlapping spheres. We conducted 3D quantitative analysis using confocal microscopy and image analysis routines specially developed for these particles. In addition, we analyzed the randomness of the process of dimpling, which was found to be volume fraction dependent.

Thursday, March 5, 2015 2:30PM - 5:30PM
Session W46 DBIO GSNP: Invited Session: Collective Behavior and Jamming in Multi-Cellular Systems
217A - Jerry Lee, National Cancer Institute
motions. Notable differences between the behaviors of different individuals can be observed in many quantities. The findings in animal foraging processes. A more detailed analysis shows that the human search patterns are more complex than simple Lévy flights or Brownian motion. We show, further, that the uncompressed epithelial layer from asthmatic donors exhibit spontaneous collective migration behavior that is similar to that observed in compressed normal cells. However, in this case the migration results from a delay in the innate tendency of the epithelial layer to transition from an unjammed phase into a jammed phase. Moreover, the unjammed state of asthmatic cells accompanies intensified adhesive forces transmitted across cell-cell junctions. We introduce a theory of critical scaling that predicts a priori the existence of the observed phase transition. Surprisingly, this theory predicts the transition to be governed by cell shape and cell-cell adhesive forces in a manner that is paradoxical, but is borne out by our direct experimental observations. Together, these findings establish an unexpected but rigorous physical foundation for further classification and investigation of epithelial layer behavior in asthma, and likely in other processes in disease or development in which epithelial dynamics play a prominent role.

This work is in part supported by the US National Science Foundation through grant DMR-1205309.
8:12AM Y11.00002 Social consensus and tipping points with opinion inertia\(^1\), CASEY DOYLE, SAMEET SREENIVASAN, BOLESLAW SZYMANSKI, GYORGY KORNISS, Rensselaer Polytechnic Institute — When opinions, behaviors or ideas diffuse within a population, some are invariably more sticky than others. The stickier the opinion, the greater an individual’s inertia to replace it with an alternative. Here we study the effect of stickiness of opinions in a two-opinion model, where individuals change their opinion only after a certain number of consecutive encounters with the alternative opinion. We focus on the scenario where initially a minority of the population adopts an opinion that is as sticky or stickier than that of the majority, and investigate how the critical size of the initial minority required to tip the entire population over to its opinion, depends on the stickiness of the minority opinion. We analyze this scenario for a complete-graph topology through simulations, and through a semi-analytical approach which yields an upper bound for the critical minority size. We present analogous simulation results for the case of the Erdos-Renyi random network. Finally, we investigate the coarsening properties of sticky opinion spreading on two-dimensional lattices, and show that the presence of stickiness gives rise to an effective surface tension that causes the coarsening behavior to become curvature-driven.

\(^1\)Supported in part by ARL NS-CTA, ARO, ONR, and NSF.

8:24AM Y11.00003 A Universal Power Law Governing Pedestrian Interactions\(^2\), IOANNIS KARAMOUCAS, Univ of Minn - Minneapolis, BRIAN SKINNER, Argonne National Laboratory, STEPHEN J. GUY, Univ of Minn - Minneapolis — Human crowds often bear a striking resemblance to interacting particle systems, and this has prompted many researchers to describe pedestrian dynamics in terms of interaction forces and potential energies. The correct quantitative form of this interaction, however, remains an open question. Here, we introduce a novel statistical-mechanical approach to directly measure the interaction energy between pedestrians. This analysis, when applied to a large collection of human motion data, reveals a simple power law interaction that is based not on the physical separation between pedestrians but on their projected time to a potential future collision, and is therefore fundamentally anticipatory in nature. Remarkably, this simple law is able to describe human interactions across a wide variety of situations, speeds, and densities. We further show, through simulations, that the interaction law we identify is sufficient to reproduce many known crowd phenomena.

\(^2\)Work at Argonne National Laboratory is supported by the U.S. Department of Energy, under contract no. DE-AC02-06CH11357. Work at the University of Minnesota is supported by MnDRIVE Initiative on Robotics, Sensors, and Advanced Manufacturing.

8:36AM Y11.00004 Finite size scaling analysis on Nagel-Schreckenberg model for traffic flow, ASHKAN BALOUCHI, DANA BROWNE, Department of Physics & Astronomy, Louisiana State University — The traffic flow problem as a many-particle non-equilibrium system has caught the interest of physicists for decades. Understanding the traffic flow properties and obtaining the ability to control the transition from the free-flow phase to the jammed phase plays a critical role in the future world of urban self-driven cars technology. We have studied phase transitions in one-lane traffic flow through the mean velocity, distributions of car spacing, dynamic susceptibility and jam persistence – as candidates for an order parameter using the Nagel-Schreckenberg model to simulate traffic flow. The length dependent transition has been observed for a range of maximum velocities greater than a certain value. Finite size scaling analysis indicates power-law scaling of these quantities at the onset of the jammed phase.

8:48AM Y11.00005 Tabletop Traffic Jams: Modeling Traffic Jams using Self Propelled Particles, VIKRANT YADAV, ARSHAD KUDROLLI, Clark University — We model behavior of traffic using Self Propelled Particles (SPPs). Granular rods with asymmetric mass distribution confined to move in a circular channel on a vibrated substrate and interact with each other through inelastic collision serve as our model vehicle. Motion of a single vehicle is observed to be composed of 2 parts, a linear velocity in the direction of lighter end of particle and a non-Gaussian velocity component of SPPs remain super-diffusive over entire range of line densities. While the collective motion at low densities is characterized by caravan following behind the slowest particle leading to clustering, at higher densities we see formation of jamming waves travelling in direction opposite to that of motion of particles.

9:00AM Y11.00006 Dynamics of influence and social balance in spatially-embedded regular and random networks\(^3\), P. SINGH, S. SREENIVASAN, B. SZYMANSKI, G. KORNISS, RPI — Structural balance - the tendency of social relationship triads to prefer specific states of polarity - can be a fundamental driver of beliefs, behavior, and attitudes on social networks. Here we study how structural balance affects deradicalization in an otherwise polarized population of leftists and rightists constituting the nodes of a low-dimensional social network. Specifically, assuming an externally moderating influence that converts leftists or rightists to centrists with probability \(p\), we study the critical number of consecutive encounters with the opposite opinion required to make an individual a centrist, and show that the critical value \(p_c\) depends on the density of interaction. We propose a semi-analytical approach that yields upper bounds on the critical values for realistic network topologies.

\(^3\)Supported in part by ARL NS-CTA, ONR, and ARO.

9:12AM Y11.00007 Self-organization of divided hierarchy, TAKASHI ODAGAKI, KEIGO KITADA, KEN TA OMIZO, Tokyo Denki University, RYU FUJIE, The University of Tokyo — There are two types of extreme form of hierarchy, one is the plutonomy where small fraction of winners and losers and many people in the middle class appear and the other a divided hierarchy where half of population become winners and the remaining half become losers. We study the emergence of the divided hierarchy in a model society which consists of bellicose individuals who always try to fight and fight with the strongest neighbor and pacific individuals who always try not to fight and when necessary fight with the weakest neighbor. In our model society, (1) individuals make random walk on a square lattice, (2) when two individuals encounter they fight each other and (3) the winner deprives wealth from the loser. By a Monte Carlo simulation, we show that there are two transitions when the population density is increased; one is a transition from the egalitarian society to a hierarchical society I where winners, losers and middle classes coexist and the other is a transition from the hierarchical society I to a high hierarchical society II where winners and losers exist but no middle classes exist, that is the divided hierarchy. We also show that clusters consisting mostly of bellicose individuals appear in the hierarchical society I.
9:24AM Y11.00008 Canonical Sectors and Evolution of Firms in the US Stock Markets1, LORIEN HAYDEN, RICKY CHACHRA, ALEXANDER ALEMI, PAUL GINSPARG, JAMES SETHNA, Cornell University — In this work, we show how unsupervised machine learning can provide a more objective and comprehensive broad-level sector decomposition of stocks. Classification of companies into sectors of the economy is important for macroeconomic analysis, and for investments into the sector-specific financial indices and exchange traded funds (ETFs). Historically, these major industrial classification systems and financial indices have been based on expert opinion and developed manually. Our method, in contrast, produces an emergent low-dimensional structure in the space of historical stock price returns. This emergent structure automatically identifies “canonical sectors” in the market, and assigns every stock a participation weight into these sectors. Furthermore, by analyzing data from different periods, we show how these weights for listed firms have evolved over time.

1This work was partially supported by NSF grants DMR 1312160, OCI 0926550 and DGE-1144153 (LXH).

9:36AM Y11.00009 Lead-lag relationships between stock and market risk within linear response theory1, STANISLAV BORYSOV2, ALEXANDER BALATSKY3, Nordita, KTH Royal Institute of Technology and Stockholm University, Roslagstullsbacken 23, SE-106 91 Stockholm, Sweden — We study historical correlations and lead-lag relationships between individual stock risks (standard deviation of daily stock returns) and market risk (standard deviation of daily returns of a market-representative portfolio) in the US stock market. We consider the cross-correlation functions averaged over stocks, using historical stock prices from the Standard & Poor’s 500 index for 1994-2013. The observed historical dynamics suggests that the dependence between the risks was almost linear during the US stock market downturn of 2002 and after the US housing bubble in 2007, remaining at that level until 2013. Moreover, the averaged cross-correlation function often had an asymmetric shape with respect to zero lag in the periods of high correlation. We develop the analysis by the application of the linear response formalism to study underlying causal relations. The calculated response functions suggest the presence of characteristic regimes near financial crashes, when individual stock risks affect market risk and vice versa.

1This work was supported by VR 621-2012-2983.
2Nanostructure Physics, KTH Royal Institute of Technology, Roslagstullsbacken 21, SE-106 91 Stockholm, Sweden
3Institute for Materials Science, Los Alamos National Laboratory, Los Alamos, NM, USA

9:48AM Y11.00010 Modeling Long-term Stock Market Prices Using Differential Equations , XIAOXIANG YANG, CONAN ZHAO, IRINA MAZILU, Washington and Lee University — Due to incomplete information available in the market and uncertainties associated with the price determination process, the stock prices fluctuate randomly during a short period of time. In the long run, however, certain economic factors, such as the interest rate, the inflation rate, and the company’s revenue growth rate, will cause a gradual shift in the stock price. Thus, in this paper, a differential equation model has been constructed in order to study the effects of these factors on the stock prices. The model obtained accurately describes the general trends in the AAPL and XOM stock price changes over the last ten years.

10:00AM Y11.00011 Social inequalities in probabilistic labor markets1, JUN-ICHI INOUE, HE CHEN, Hokkaido University — We discuss social inequalities in labor markets for university graduates in Japan by using the Gini and k-indices [1]. Feature vectors which specify the abilities of candidates (students) are built-into the probabilistic labor market model [2]. Here we systematically examine what kind of selection processes (strategies) by companies according to the weighted feature vector of each candidate could induce what type of inequalities in the number of informal acceptances leading to a large mismatch between students and companies.


1This work was financially supported by Grant-in-Aid for Scientific Research (C) of Japan Society for the Promotion of Science (JSPS) No. 2533027803 and Grant-in-Aid for Scientific Research on Innovative Area No. 25120013.

10:12AM Y11.00012 Cascades in the Threshold Model for varying system sizes1, PANAGIOTIS KARAMPOURNIOTIS, SAMEET SREENIVASAN, BOLESLAW SZYMANSKI, GYORGY KORNIS, Rensselaer Polytechnic Institute — A classical model in opinion dynamics is the Threshold Model (TM) aiming to model the spread of a new opinion based on the social drive of peer pressure. Under the TM a node adopts a new opinion only when the fraction of its first neighbors possessing that opinion exceeds a pre-assigned threshold. Cascades in the TM depend on multiple parameters, such as the number and selection strategy of the initially active nodes (initiators), and the threshold distribution of the nodes. For a uniform threshold in the network there is a critical fraction of initiators for which a transition from small to large cascades occurs, which for ER graphs is largely independent of the system size[1]. Here, we study the spread contribution of each newly assigned initiator under the TM for different initiator selection strategies for synthetic graphs of various sizes. We observe that for ER graphs when large cascades occur, the spread contribution of the added initiator on the transition point is independent of the system size, while the contribution of the rest of the initiators converges to zero at infinite system size. This property is used for the identification of large transitions for various threshold distributions.

1Supported in part by ARL NS-CTA, ARO, ONR, and DARPA.

10:24AM Y11.00013 Collective behavior in the evolution of scientific research interests1, TAO JIA, Department of Physics and Computer Science, Rensselaer Polytechnic Institute, Troy, NY, 12180 USA, DASHUN WANG, IBM Thomas J. Watson Research Center, Yorktown Heights, NY, 10598 USA, GYORGY KORNIS, Department of Physics, Rensselaer Polytechnic Institute, Troy, NY, 12180 USA, BOLESLAW SZYMANSKI, Department of Computer Science, Rensselaer Polytechnic Institute, Troy, NY, 12180 USA — Scientific research is strongly associated with the researchers’ interests in particular areas or disciplines. On one hand, the stable research interest enables one to gain the expertise by repetitive practices specialized in a certain field. On the other hand, occasional change on the area of interest may reinvigorate one’s research. To date, we lack a quantitative understanding on the likelihood of the research interest change, the consequent impact and the internal mechanism of this dynamical process. Here we analyze the publication records of over 14,000 scientists and quantitatively measure their research interest transitions. Our result shows that the fraction of scientists drops exponentially with the extent of transition, indicating that most scientists keep their interests quite stable. While it is rare, those who change demonstrate a higher-than-average chance to increase the productivity and impact. We propose a theoretical model that reproduces not only the observations in interest evolution but also the patterns of publication activities, allowing us to probe the short-term benefits of exploitation on the established field and the long-term returns of exploration on the new lines of inquiry.

1Supported in part by ARL NS-CTA, ONR and ARO.
In this talk a model for earthquake fault systems undergoing hydraulic fracturing will be introduced. The question of how seismic failure events lead to large seismic events in regions with a large amount of hydraulic fracturing activity has been of great interest in recent media reports of earthquake events in Oklahoma. In this talk we will present this novel apparatus and discuss initial results.

Each of ring can be moved independently which permits us to impose any desired shear profile. The circular geometry allows access to any strain value. The forces between grains are measured using reflective photoelasticity. This talk will present this novel apparatus and discuss initial results.

Nevertheless, the value of $\phi_J$ as a function of the shear profile or the strain necessary to observe jamming remain poorly understood because of the experimental complexity to access high strain without shear band. We present a novel 2D periodic shear apparatus made of 21 independent, aligned and mirrored glass rings. Each of ring can be moved independently which permits us to impose any desired shear profile. The circular geometry allows access to any strain value. The forces between grains are measured using reflective photoelasticity. This talk will present this novel apparatus and discuss initial results.

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We obtain quantitative agreement between experimental measurements and theoretical predictions for both internally generated acoustic noise and externally applied pressures. We interpret inter-particle friction as an additional source of acoustic noise. At high strain rates, it promotes strain localization and may explain long-term persistence of shear bands in natural faults. Shape effects are modeled by an orientational bias that describes grain interlocking and geometric frustration. We interpret inter-particle friction as an additional source of acoustic noise. At high strain rates, it promotes strain localization and may explain long-term persistence of shear bands in natural faults. Shape effects are modeled by an orientational bias that describes grain interlocking and geometric frustration. We interpret inter-particle friction as an additional source of acoustic noise.
Influence the dynamic properties in a predictable manner, fully captured by the theory which an approximate self-consistent description of the simulated self-diffusion properties can be derived. Here we compare the theoretical and simulated results.

Characterized by short-time self-diffusion coefficients Lab, MAGDALENO MEDINA NOYOLA, Universidad Autonoma de San Luis Potosi — In this work we study the self-diffusion properties of a liquid of hollow spheres and eggs for the shells and yolk, respectively. Using a softened version of these interparticle potentials we perform Brownian dynamics simulations to determine the mean squared displacement and intermediate scattering function of the yolk-shell complex. These results can be understood in terms of a set of effective Langevin equations for the interacting shell particles, pre-averaged over the yolk's degrees of freedom, from which an approximate self-consistent description of the simulated self-diffusion properties can be derived. Here we compare the theoretical and simulated results between them, and with the results for the same system in the absence of yolk. We find that the yolk, which have no effect on the shell-shell static structure, influence the dynamic properties in a predictable manner, fully captured by the theory.

Abstract withdrawn —

Shear flow of angular grains: Acoustic effects and stick-slip instabilities

Charles K. C. LIEOU, University of California, Santa Barbara, AHMED E. ELBANNA, University of Illinois at Urbana-Champaign, JAMES S. LANGER, JEAN M. CARLSON, University of California, Santa Barbara — We propose a model for stick-slip instabilities in a sheared granular medium composed of frictional grains. We show that friction between particles is essential in producing stick-slip failure at inter-mEDIATE shear rates, even if the material is rate-strengthening in character in the limit of large shear rates. In addition, externally generated acoustic vibrations promote stick-slip instabilities at low shear rates, but suppresses it at low confining pressure. We construct separate phase diagrams that indicate the parameter regimes for which stick-slip occurs, in the presence and absence of acoustic vibrations. These results connect the microscopic physics to macroscopic stress dynamics, elucidate the role of interparticle fractional interactions and acoustic vibrations on frictional dynamics, and provide important insight on the physical origin of earthquake rupture and seismic slip. Our findings show good agreement with laboratory experiments on simulated fault gouge.

Model-free test for nonlocal effects in jammed matter

Brian Tighe, Karsten Baumgarten, TU Delft — There is growing evidence that the mechanical response of materials close to the jamming transition is nonlocal; i.e. the deformation (rate) at one position is influenced by stresses at a distance. Nonlocal models successfully describe flow in a number of geometries where conventional local models fail not just quantitatively but qualitatively. Research to date has advanced by proposing a nonlocal model, which generally contains free parameters, and fitting its predictions to experimental or numerical data. This makes it difficult to distinguish the general effects of nonlocality from the details of a particular model. We take a different approach by introducing a model-free test for nonlocality. The test is easily implemented in computer simulations and provides a quantitative measure of the amplitude of nonlocal effects, without assuming a model for the nonlocal mechanics of the material. We demonstrate this method in several model systems, including soft spheres near jamming.

ABSTRACT WITHDRAWN —

Shear flow of angular grains: Acoustic effects and stick-slip instabilities

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Funded by the Dutch Organization for Scientific Research (NWO).
8:00AM Y46.00001 Bacterial transport: From flagellar mechanics to unmixing. JEFFREY GUASTO, Tufts University — Swimming bacteria play integral roles in processes ranging from infections in the human body to bioremediation in the environment. Understanding the physical mechanisms underlying bacterial transport is key to controlling these important processes. Using high-speed video microscopy and microfluidic devices, we uncover surprising mechanisms at the level of individual cells that lead to complex motility patterns. We describe a novel mechanism enabling bacteria with a single flagellum to reorient, whereby their propulsive thrust induces a buckling instability in their flagellum. We also show that hydrodynamic shear produces striking spatial heterogeneity in suspensions of otherwise randomly-swimming bacteria. This shear-induced ‘unmixing’ phenomenon directly impacts bacterial survival strategies, by suppressing chemotaxis and enhancing surface attachment.

8:36AM Y46.00002 Swimming dynamics of flagellated bacteria in liquid crystal. ANDREY SOKOLOV, Argonne National Laboratory — A flagellated bacterium swimming in water generates a flow with a typical scale of its body length. Anisotropy of the surrounding liquid significantly affects the swimming dynamics of bacteria and modifies the flow pattern created by a single bacterium. Using the particle tracking technique and flow reconstruction method we investigated the structure of the flow generated by bacteria and pairwise interactions between bacteria in liquid crystals. We demonstrated that while the rotation rate of bacterial flagella is reduced by an order of magnitude due to increased viscosity, the bacteria swimming speed is slowed only by 25-30%. Due to the strong anisotropy of viscosity in liquid crystal the bacteria-induced flow is localized along a bacterial body: the flow along a line coaxial with the bacterial body is much stronger than in perpendicular direction and decays rather slowly. We found that interaction between flagella bunches of two closely-packed bacteria is negligible and the observed convergence of the swimming speeds and flagella waves may occur due to viscoelastic interaction between bacterial bodies.

9:12AM Y46.00003 Quantifying and controlling microbial swimming. JORN DUNKEL, MIT — Interactions between swimming cells, surfaces and fluid flow are essential to many microbiological processes, from the formation of biofilms to the fertilization of human egg cells. Yet, relatively little remains known quantitatively about the physical mechanisms that govern the response of bacteria, algae and sperm cells to flow velocity gradients and solid surfaces. A better understanding of cell-surface and cell-cell interactions promises new biological insights and may advance microfluidic techniques for controlling microbial and sperm locomotion. In this talk, I will summarize our recent efforts to quantify the surface interactions of bacteria, unicellular green algae and mammalian spermatozoa. This joint experimental and theoretical work shows that the subtle interplay of hydrodynamics and surface interactions can stabilize collective bacterial motion, that direct ciliary contact interactions dominate surface scattering of eukaryotic biflagellate algae, and that rheotaxis combined with steric surface interactions provides a robust long-range navigation mechanism for sperm cells.

9:48AM Y46.00004 Entrapment, escape, and diffusion of swimming bodies in complex environments. SAVERIO SPAGNOLIE, University of Wisconsin-Madison — We will begin by addressing the hydrodynamic entrapment of a self-propelled body near a stationary spherical obstacle. Simulations of model equations show that the swimmer can be trapped by a spherical colloid larger than a critical size, that sub-critical interactions tend to result in short residence times on the surface, and that the basin of attraction around the colloid is set by a power-law size of the swimmer. Simulations of model equations show that the swimmer can be trapped by a spherical colloid larger than a critical size, that sub-critical interactions tend to result in short residence times on the surface, and that the basin of attraction around the colloid is set by a power-law size of the swimmer. Simulations of model equations show that the swimmer can be trapped by a spherical colloid larger than a critical size, that sub-critical interactions tend to result in short residence times on the surface, and that the basin of attraction around the colloid is set by a power-law size of the swimmer.

10:24AM Y46.00005 XXXX. MICHAEL SHELLEY, Courant Institute of Mathematical Science, NYU — No abstract available.

8:00AM Y49.00001 Yielding, Plasticity, and Microstructure in a 2D Jammed Material under Shear Deformation. PAULO ARRATIA, NATHAN KEIM, University of Pennsylvania — In this talk, we discuss an experimental investigation on the yielding and plastic deformation of disordered solids. Experiments are performed on colloidal particles that are adsorbed at an oil-water interface and form a dense disordered monolayer. The rheological properties (G', G'') of this dense monolayer are obtained in a custom-built surface stress rheometer that uses a magnetic needle within the material. This configuration allows for the simultaneous characterization of both microstructure (tracking ~ 10^5 particles) and bulk rheology. Results show that for oscillatory shear below a certain strain amplitude, the microstructure becomes reversible after a transient. Above this strain amplitude, the microstructure continues to evolve through many irreversible events. We argue that this boundary between a reversible and irreversible steady state is a yielding transition, and that our experiments measure a meaningful yield stress. Further, we find that reversible plastic deformation is possible. That is, the material can reorganize itself so that the link between plasticity and irreversibility is broken: the material flows slightly, and yet at the end of each deformation cycle, it is exactly unchanged.

8:12AM Y49.00002 Stress localization, stiffening, and yieldning in a model colloidal gel. EMANUELA DEL GADO, Department of Physics and Institute for Soft Matter Synthesis and Metrology, Georgetown University, JADER COLOMBO, Department of Civil, Environmental and Geomatic Engineering, ETH Zurich, GEORGETOWN UNIVERSITY COLLABORATION, ETH ZURICH COLLABORATION — We investigate the yielding of a model colloidal gel using numerical simulations and different shear protocols. Under increasing deformation, the elastic regime is followed by a significant stiffening before yielding takes place. A space-resolved analysis of deformations and stresses unravel how the complex load curve observed is the result of stress localization and that the yielding can take place by breaking a very small fraction of the network connections. The strong localization of tensile stresses triggers the breaking of a few network nodes at around 30% of strain and increasing the deformation further favors breaking but also shear-induced bonding, eventually leading to the damage and the reorganization of the gel structure upon yielding. In particular, at low enough shear rates, density and velocity profiles display significant spatial inhomogeneity during yielding in agreement with experimental observations.
8:24AM Y49.00003 Structure and Rheology of Concentrated Emulsions
JUNG-REN HUANG, YI-CIAN LAI, CHE-HAO OU, Physics Department, National Taiwan Normal University, JIH-CHIANG TSAIL, Institute of Physics, Academia Sinica — We construct a shearing apparatus combining light scattering and stress measurement to study the structure and rheology of concentrated monodisperse emulsions. The emulsions are subjected to oscillatory shear of variable amplitude and frequency. The light scattering data reflect droplet deformation as well as shear history-dependent inter-droplet structures. The stress measurements display pseudoplasticity near zero shear rate and shear-thinning behavior at finite shear rates. In addition, time-resolved, synchronous measurement of light scattering and rheology reveals detailed information about the complex structure-rheology relationship of emulsions. Shear disorder the droplets at low and high shear rates but induces order at medium shear rates. Furthermore, the effective viscosity increases as the degree of inter-droplet order decreases.

This work is supported by Taiwan MOST grant 100-2112-M-003-001-MY3.

8:36AM Y49.00004 The viscous forces acting on quasi-2D emulsions under fast flow
CARLOS ORELLANA, XIA HONG, JANNA LOWENSOHN, ERIC WEEKS, Emory University — We study the flow of dense emulsions in a quasi-two-dimensional sample chamber. Our samples are oil-in-water emulsions confined between two close-spaced parallel plates, so that the oil droplets are deformed into pancake shapes. By means of microscopy, we measure the droplet positions and their deformation, which is related to the forces on the individual droplet. Here we study the velocity dependence of the force on the droplets, and that the main contribution is from the viscous friction between droplets rather than from viscous drag from the two confining plates. Our results can be applied to study the forces and rearrangements in fast flow in amorphous materials.

8:48AM Y49.00005 Linear and nonlinear rheology of dense emulsions across the glass and the jamming regimes
FRANK SCHEFFOLD, CHI ZHANG, Department of Physics, University of Fribourg, THOMAS G. MASON, Department of Chemistry and Biochemistry, University of California Los Angeles — We discuss the linear and nonlinear rheology of concentrated silicone oil-in-water emulsions, amorphous disordered solids composed of repulsive and deformable soft colloid spheres. Based on recent results from simulation and theory, we derive quantitative predictions for the dependences of the elastic shear modulus and the yield stress on the effective droplet volume fraction [1]. The remarkable agreement with experiments we observe supports the scenario that the repulsive glass and the jammed state can be clearly identified in the rheology of soft spheres at finite temperature while crossing continuously from a liquid to a highly compressed yet disordered solid. We show that the onset of elasticity due to entropic contribution can be described by a quasi-equilibrium analytical model of linear elasticity that includes energetic contributions from entropy and soft interfacial deformation [2]. In a second set of experiments we use confocal microscopy to monitor the structure and dynamics of emulsion droplets while crossing the glass and the jamming transition. [3]. [1] F. Schefold et al., J. Phys.: Cond. Mat. 25, 502101 (2013), [2] T. G. Mason et al., Soft Matter 10, 7109 (2014) [3] C. Zhang et al., http://arxiv.org/abs/1411.0314

9:00AM Y49.00006 The Role of Free Surfaces on Plastic Deformation of Colloidal Micropillars
DANIEL STRICKLAND, ALEXANDER KLEBNIKOV, University of Pennsylvania, Department of Materials Science and Engineering, JYO LYN HOR, DAEEYON LEE, University of Pennsylvania, Department of Chemical and Biomolecular Engineering, DANIEL GIANOLA, University of Pennsylvania, Department of Materials Science and Engineering — The effect of free surfaces on the strength and deformation behavior of amorphous solids remains an area of intensive research in materials science. We present experiments on the evolution of particle-level strain in amorphous colloidal micropillars compressed uniaxially. The unique micropillar geometry allows us to study the effect of free surfaces, which are believed to be fertile sites for STZ activity, on deformation behavior. The micropillars, which are composed of fluorescent 3 μm PMMA particles, are suspended in a fluid so that we can use laser scanning confocal microscopy to image through the micropillar at each increment of macroscopic strain. By employing particle-identification and tracking algorithms, we are able to track the positions of more than 100,000 individual particles during the duration of a compression experiment. Particle-level position information allows us to quantify the spatiotemporal evolution of microscopic strain with macroscopic strain and explore differences in deformation behavior between bulk and surface regions.

9:12AM Y49.00007 Echoes in x-ray speckles track nanometer-scale plastic events in colloidal gels under shear
ROBERT LEHENY, Johns Hopkins University, MICHAEL ROGERS, University of Ottawa, KUI CHEN, Johns Hopkins University, LUKAS ANDRZEJEWSKI, University of Ottawa, SURESH NARAYANAN, Argonne National Laboratory, SUBRAMANIAN RAMAKRISHNAN, FAMU, JAMES HARDEN, University of Ottawa — Any solid under applied stress possesses an elastic limit above which it yields. The microscopic signatures of yield are irreversible changes to the material's structure. We describe x-ray photon correlation spectroscopy experiments on a concentrated nanocolloid gel subject to in situ oscillatory shear strain that provide information about the spatial character of rearrangements above yielding at the nanometer scale. The oscillatory strain causes periodic echoes in the x-ray speckle pattern, creating peaks in the intensity autocorrelation function. The peak amplitudes are attenuated above a threshold strain, signaling the onset of irreversible particle rearrangements. The gel displays strain softening well below the threshold, indicating a range of strains at which deformations are nonlinear but reversible. Above the threshold strain, the peak amplitudes decay exponentially with the number of shear cycles, demonstrating that all regions in the sample are equally susceptible to yielding and that the probability of a region yielding is independent of previous shear history. The wave-vector dependence of the decay rate reveals a power-law distribution in the size of rearrangement regions, suggesting a nonequilibrium critical transition at yielding.

9:24AM Y49.00008 Yielding of colloidal gels under steady and oscillatory shear
GEORGE PETEKIDIS, EMMAELE MOGHIMI, NICK KOUMAKIS, IESL-FORTH, FORTH TEAM — The structural and rheological properties of intermediate volume fraction colloidal polymer gels are examined during and after steady and oscillatory shear flow using rheometry, confocal microscopy, light scattering and Brownian Dynamics simulations. Our main objective is to rationalize the microscopic mechanisms through which one can tune the mechanical properties of such metastable colloidal gels by imposing different types of external shear and flow. Experimentally, the gels consist of model hard sphere particle dispersions of \( \varphi = 0.44 \) with the addition of non-adsorbing linear chains, while BD simulations are conducted for hard spheres with the superposition of an AO potential for depletion attractions. Structural analysis shows that variation of the applied shear rate produces strong changes in the structure of the gels both when under shear and during gel reformation at cessation. Larger rates are characterized by disperse particles and the total breakage of structures at rest, which after cessation evolve with time into strong solids with relatively homogeneous structures. However, smaller rates show large inhomogeneous structures under flow, which do not evolve after cessation and additionally exhibit reduced elasticity and as such are weaker solids. Furthermore oscillatory shear is far more efficient than steady shear creating gels with stronger differences in their elastic modulus. Thus by tuning the way a gel is sheared, one may vary the final strength and structure of the resulting gel. Work in collaboration with R. Besseling, W. C. K. Poon and J. F. Brady.
— 9:36AM Y49.00009 Matrix polymer species have distinct effects on the mechanics of bacterial biofilms , KRISTIN KOVACH, MEGAN DAVIS-FIELDS, VERNITA GORDON, Univ of Texas, Austin — Biofilms are aggregates of microorganisms embedded in a self-produced extracellular polymer matrix. The matrix confers protection to these microorganisms against mechanical and chemical stresses that they may experience in their environment. The bacterium Pseudomonas aeruginosa is widely used as a model biofilm-forming organism because it is an opportunistic human pathogen common in hospital-acquired infections, in chronic wounds, and in cystic fibrosis lung disease. P. aeruginosa strain PA01 forms biofilms that are primarily structured by the extracellular polysaccharides Pel and Psl. Using bulk rheological measurements, we show that these polysaccharides each play a unique role in the mechanical robustness of the biofilm. Pel increases the elastic storage modulus while Psl increases the ductility of the biofilm. Increased expression of either Psl or Pel increases the yield stress by about the same amount. Identifying the mechanism(s) by which these polymers contribute to the mechanical toughness of the biofilm could allow new approaches to effective biofilm clearance, by revealing targets for disruption that would weaken the biofilm.

9:48AM Y49.00010 ABSTRACT WITHDRAWN —

10:00AM Y49.00011 A simple feature of yielding of dense suspensions of soft micro-hydrogel particles , KENJI URAYAMA, Dept. Macromol. Sci. & Eng., Kyoto Institute of Technology, TAKU SAEKI, SHEN CONG, Dept. Mater. Chem., Kyoto University, SYOTA URATANI, Dept. Macromol. Sci. & Eng., Kyoto Institute of Technology, TOSHIKAZU TAKIGAWA, Dept. Mater. Chem., Kyoto University, MASAKI MURAI, DAI SUKE SUZUKI, Shinsu University — The highly dense suspensions of soft micro-hydrogels with a narrow size distribution, which form a regular lattice structure, exhibit a simple feature in the yielding behavior: the yield strain $\gamma_\text{y}$ [ca. 2.5% and ca. 4.8% for PNIPMA] and PNIPA hydrogel particles, respectively is nearly independent of the cross-link concentration, particle diameter, and particle concentration $c$ in the limited $c$ range examined here, and $\gamma_\text{y}$ is almost constant in a wide range of equilibrium shear modul over two orders of magnitude. Further, no appreciable difference in $\gamma_\text{y}$ is observed in the dense pastes with crystalline and glassy structures which are formed by mono- and bidisperse microgels, respectively. In addition, the highly dense suspensions of NIPA core–NIPMA shell microgels are similar in $\gamma_\text{y}$ to those of NIPMA microgels. These results indicate that $\gamma_\text{y}$ for the highly dense suspensions of soft micro-hydrogels depends primarily on the kind of constituent polymer near the particle surface. The yield strain $\gamma_\text{y}$ is expected to be governed by short-range interactions such as adhesion and friction. [Reference] K. Urayama, T. Sae, S. Cong, S. Uratani, T. Takigawa, M. Murai, Suzuki, Soft Matter, DOI: 10.1039/c4sm01841a.

10:12AM Y49.00012 Plasticity and fracture of curved colloidal crystal shells , CARLOTTA NEGRI, ALESSANDRO SELLERIO, IENI CNR, Institute for Energetics and Interphase, National Research Council, Via R. Cozzi 53, Milano 20125, Italy, M.-CARMEN MIGUEL, Department of Physics Fundamental, Facultad de Fisica, Universidad de Barcelona, Av. Diagonal 645, 08028 Barcelona, Spain, STEFANO ZAPPERI, IENI CNR, Institute for Energetics and Interphase, National Research Council, Via R. Cozzi 53, Milano 20125, Italy — Colloidal shells display peculiar equilibrium properties resulting from the interplay between geometrically necessary topological defects and curvature induced stresses. Here we report the results of large scale numerical simulations of the deformation of colloidal particles arranged in crystalline shells showing that the dynamics of topological defects exhibits a rich and non-trivial phenomenology. Depending on the mode of deformation, we observe intermittent plastic deformation with collective particle reorganization mediated by the proliferation of disclinations pairs and grain boundary reorientation or abrupt structural failure induced by crack nucleation at defects. Our work clarifies the role of topology and curvature in the mechanical deformation of crystalline shells.

Friday, March 6, 2015 11:15AM - 2:15PM — Session Z3 GSNP: Invited Session: Thermodynamics of Information Processing 002AB - Massimiliano Esposito, University of Luxembourg

11:15AM Z3.00001 Stochastic thermodynamics of information processing , ANDRE CARDOSO BARATO, Universitatet Stuttgart — We consider two recent advancements on theoretical aspects of thermodynamics of information processing. First we show that the theory of stochastic thermodynamics can be generalized to include information reservoirs. These reservoirs can be seen as a sequence of bits which has its Shannon entropy changed due to the interaction with the system. Second we discuss bipartite systems, which provide a convenient description of Maxwell’s demon. Analyzing a special class of bipartite systems we show that they can be used to study cellular information processing, allowing for the definition of an entropic rate that quantifies how much a cell learns about a fluctuating external environment and that is bounded by the thermodynamic entropy production. Refs: [1] A. C. Barato and U. Seifert, Phys. Rev. Lett. 112, 090601 (2014); [2] A. C. Barato and U. Seifert, Phys. Rev. E 90, 042150 (2014); [3] A. C. Barato, D. Hartich, and U. Seifert, New J. Phys. 16, 103024 (2014).

11:51AM Z3.00002 High-Precision Test of Landauer’s Principle in a Feedback Trapootnote{Supported by the National Science and Engineering Research Council of Canada (NSERC)} , JOHN BECHHOEFER	extsuperscript{2}, Simon Fraser University — Landauer’s principle, formulated in 1961, postulates that irreversible logical or computational operations such as memory erasure require work, no matter how slowly they are performed. For example, to “reset to one” a one-bit memory requires at least $kT \ln 2$ of work, which is dissipated as heat. Bennett and, independently, Penrose later pointed out a link to Maxwell’s Demon: Were Landauer’s principle to fail, it would be possible to repeatedly extract work from a heat bath. We report tests of Landauer’s principle in an experimental system consisting of a charged colloidal particle in water. To test stochastic thermodynamic ideas, we create a time-dependent, “virtual” double-well potential via a feedback loop that is much faster than the relaxation time of the particle in the virtual potential. In a first experiment, the probability of “erasure” (resetting to one) is unity, and at long cycle times, we observe that the average work is compatible with $kT \ln 2$. In a second, the probability of erasure is zero; the system may end up in two states, and, at long cycle times, the average measured work tends to zero. In individual cycles, the work to erase can be below the Landauer limit, consistent with the Jarzynski equality.

12:27PM Z3.00003 Information Processing and the Second Law of Thermodynamics: An Inclusive Hamiltonian Approach , SEBASTIAN DEFFNER, Los Alamos Natl Lab — We obtain generalizations of the Kelvin-Planck, Clausius, and Carnot statements of the second law of thermodynamics for situations involving information processing. To this end, we consider an information reservoir (representing, e.g., a memory device) alongside the heat and work reservoirs that appear in traditional thermodynamic analyses. We derive our results within an inclusive framework in which all participating elements – the system or device of interest, together with the heat, work, and information reservoirs – are modeled explicitly by a time-independent, classical Hamiltonian. We place particular emphasis on the limits and assumptions under which cyclic motion of the device of interest emerges from its interactions with work, heat, and information reservoirs. Finally, our findings are illustrated with a simple, analytically solvable example – a quantum Maxwell demon.

\footnote{In collaboration with Yonggun Jun and Momčilo Gavrilov.}

\footnote{Supported by the National Science and Engineering Research Council of Canada (NSERC)}
axis is perpendicular to the direction of gravity. The drum and spheres first rotate as a solid body, and the slope of the sphere packing increases until the

However, we find that how the lattice rigidifies as braces are added depends on the lattice architecture in interesting ways. We study this problem in both

Rigidity percolation, the emergence of rigidity as bonds are randomly added to a structure, has been studied using various models, yielding a rich variety of

The conditional probability $P(\phi|\phi_g)$ to find a specific value of $\phi$ given a global packing fraction $\phi_g$ is found to be independent of $\alpha$ and $X$. Our results demonstrate that for frictional particles a local approach is not only a theoretical requirement but also feasible.

11:39AM Z44.00003 Mechanical Response in Particulate Media, NIRANJAN WARNAKULASOROYI, LEO SILBERT, Department of Physics, Southern Illinois University Carbondale, 62901, USA — We study the mechanical behavior of granular particle system in two dimensions in response to a dynamical intruder using computer simulations. We created mechanically stable granular packings of bidisperse discs with various coefficients of friction spanning several orders of magnitude and packing fractions in the vicinity above the critical packing fraction $\phi_c$. For each packing, we find the critical force $F_c$, the minimum force required to induce motion of a probe particle that we are trying to drag through the packing. Below the critical force the probe particle does not sustain continued motion. Just at the critical force, the probe particle moves through the system strongly intermittently. When the force is slightly larger than the $F_c$, the probe particle with well-defined average velocity. We find how the critical force and the average probe velocity depend on the packing pressure and particle frictions.

11:51AM Z44.00004 Rigidity percolation in generic and regular isostatic lattices, LEYOU ZHANG, D. ZEB ROCKLIN, Univ of Michigan - Ann Arbor, BRYAN CHEN, Institutu-Lorentz, Leiden University, XIAOMING MAO, Univ of Michigan - Ann Arbor — Rigidity percolation, the emergence of rigidity as bonds are randomly added to a structure, has been studied using various models, yielding a rich variety of behaviors including continuous/discontinuous transitions as well as mean field/anomalous scalings. Here we present our study of rigidity percolation in isostatic lattices, which are at the verge of mechanical instability and thus adding a vanishing fraction of next-nearest-neighbor bonds ("braces") can rigidify the lattice. However, we find that how the lattice rigidifies as braces are added depends on the lattice architecture in interesting ways. We study this problem in both regular (periodic, with bonds following straight lines) and generic (sites are randomly moved, keeping only the topology of the connectivity) versions of isostatic square and Kagome lattices via simulation. We discover that (1) rigidity percolation in generic isostatic lattices is discontinuous, with a sudden emergence of a rigid bulk, before which no stress can appear, sharing intriguing similarities with jamming, and (2) regular isostatic lattices, in contrast, show mixed features of continuous and discontinuous transitions. We propose analytic theories to explain our observations.

12:03PM Z44.00005 Experimental avalanches in a two-dimensional rotating drum: Universality or a first-order phase transition?1, ALLINE HUBARD, CUNY Graduate Center and Levich Institute and Physics Department of City College of New York, COREY O’HERN, Department of Mechanical Engineering & Materials Science, Department of Applied Physics, and Department of Physics, Yale University, MARK SHATTUCK, CUNY Graduate Center and Levich Institute and Physics Department of City College of New York — We study experimentally the dynamics of steel spheres in a quasi-two-dimensional rotating drum to investigate whether avalanches occur as continuous or first-order transitions. In our experiments, monodisperse steel spheres are confined within a cylindrical region between the glass walls of the drum, and the drum rotation axis is perpendicular to the direction of gravity. The drum and spheres first rotate as a solid body, and the slope of the sphere packing increases until the packing becomes unstable. The avalanche proceeds until the system finds another stable packing. Using high-speed video, we track the particle displacements during each avalanche to quantify the statistics of the avalanche sizes and durations as a function of the rotation rate and particle size distribution. We find that the avalanche size and duration distributions display power-law scaling over several decades, which suggests universal behavior in this system.

NSF-DMR-PREM-0934206
12:15PM Z44.00006 Mean-field approach for random close packings of non-spherical and adhesive particles. ADRIAN BAULE, School of Mathematical Sciences, Queen Mary University of London, ROMAIN MARI, Levich Institute, City College of New York, LIN BO, LOUIS PORTAL, Levich Institute and Physics Department, City College of New York, WENWEI LIU, SHUIQING LI, Department of Thermal Engineering, Tsinghua University, HERMAN MAKSE, Levich Institute and Physics Department, City College of New York — Random packings of objects of a particular shape are ubiquitous in science and engineering. However, such jammed matter states have eluded any systematic theoretical treatment due to the strong positional and orientational correlations involved. Here, a mean field theory based on a statistical treatment of the Voronoi volume is presented, which allows for the calculation of the random close packing of spherical as well as non-spherical hard particles. The extension of the framework to packings of adhesive particles is discussed. A phase diagram is presented that describes non-spherical and adhesive particles in terms of analytic continuations from the spherical random close packing.

12:27PM Z44.00007 Jamming aids jumping in granular media1. JEFFREY AGUILAR, Georgia Tech School of Mechanical Engineering, ANDRAS KARSAI, DANIEL I. GOLDMAN, Georgia Tech School of Physics — Little is known about the impulsive force and flow fields generated during jumping on granular media. We use a simple robot jumping on poppy seeds to explore maneuvers that induce jammed (non-yielding) states, and find sensitive dependence of jumping performance to movement strategy. On loose packings (volume fraction $\phi = 0.57$), a preliminary hop followed by a delay (“delayed stutter jump”) improves the height of a push-off maneuver (“single jump”). Constant speed intrusion force measurements suggest that reentry of the foot during the preliminary hop reintroduces high surface resistance. An optimal delay time ($t \approx 50$ ms) leads to maximal jump heights, while a short delay time ($t \approx 0$ ms) produces the lowest jumps. Velocimetry of grain flow reveals that non-delay stutters induce fluid-like granular states into which the robot sinks before jamming occurs, lowering jump heights. While simulations of single and delayed stutter jumps are well described using a frictional (depth dependent) plus drag (velocity dependent) penetration resistance, this model does not capture stutter jump performance at low $\phi$. However, addition of an added mass term improves agreement, signaling the need for a more complex reactive force theory in impulsively forced granular media.

1This work is funded by NSF Physics of Living Systems CAREER, Burroughs Wellcome Fund, and ARO.

12:39PM Z44.00008 Exploring the Bernoulli effect on airfoils in a granular flow. YASIN KARIM, ERIC CORWIN, University of Oregon — The Bernoulli effect describes the decrease in pressure that results from a fluid accelerating over an airfoil. While granular materials lack many of the features of fluids (i.e. they are compressible, do not have a well-defined viscosity, and are non-cohesive) they nonetheless can be made to flow. We report on experiments carried out to study Bernoulli lift in granular flows as a function of flow speed, density, airfoil shape. Using velocimetry and force sensors we probe the existence of a Bernoulli lift on an airfoil as glass beads flow around it in a quasi-two dimensional system.

12:51PM Z44.00009 Non-crystalline states in a 2D dusty plasma. JUAN-JOSE LIETOR-SANTOS, CAO CONG, JUSTIN BURTON, Emory University — When suspended in a plasma, colloidal particles become negatively charged due to a preponderance of collisions with free electrons. If the plasma is weakly-ionized, the resulting repulsive electrostatic forces cause the particles to self-organize into a single 2D layer in the plasma sheath near a surface. At high concentrations and particle charging, a hexagonal crystalline lattice is formed which supports the propagation of underdamped, phonon-like waves. This “dusty plasma” is an ideal model system to study low-temperature dynamics in solids, where the individual particle motions can be visualized and tracked [1]. Here we report the creation of non-crystalline states in a dusty plasma by combining two particle species of different size and material density. By finely-tuning these variables, we show that both particle populations lie in the same plane, leading to a 2D amorphous structure which can be used to study the dynamics of glassy and jammed systems at low temperatures and frequencies.