The Abdus Salam
International Centre for Theoretical Physics

United Nations
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Workshop on
Driven States in Soft and Biological Matter
18 - 28 April 2006

(ref. smr. 1746)

Co-sponsored by the
National Centre for Biological Sciences, Bangalore

LIST

ABSTRACTS OF TALKS

The Abdus Salam
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Workshop on Driven States in Soft and Biological Matter
18 - 28 April 2006 (ref. smr. 1746)

Armand <u>AJDARI</u>
Laboratoire de Physico-Chimie Theorique
UMR CNRS-ESPCI 7083, ESPCI
10 rue Vauquelin, F-75005 Paris, France

Title

Microfluidic-evaporators for dynamically controlled concentration and induction of dense phases.

Abstract

This talk will report on the development of new microfluidic tools that permit to concentrate soft condensed matter system in a temporally controlled and gentle way. Mesophases and crystalline phases can be induced reversibly, which opens a path for kinetic studies of pahse transitions, as well as parallel screening of phase properties of mixtures for formulation/materials engineering.

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Igor ARONSON
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Title

Large-scale pattern formation in active particles systems: from interacting microtubules to swimming bacteria

Abstract

We consider two active particles systems exhibiting large-scale collective behavior: microtubules interacting with molecular motors and hydrodynamically entrained swimming bacteria. Starting from a generic stochastic microscopic model of inelastically colliding polar rods with an anisotropic interaction kernel, we derive set of equations for the local rods concentration and orientation. Above certain critical density of rods the model exhibits orientational instability and onset of large-scale coherence. For the microtubules and molecular motors system we demonstrate that the orientational instability leads to the formation of vortices and asters seen in recent experiments. Similar approach is applied to colonies of swimming bacteria Bacillus subtilis confined in thin fluid film. The model is formulated in term of two-dimensional equation for local density and orientation of bacteria coupled to the low Reynolds number Navier-Stokes equation for the fluid flow velocity. The collective swimming of bacteria is represented by additional source term in the Navier-Stokes equation. We demonstrate that this system exhibits formation of dynamic large-scale patterns with the typical scale determined by the density of bacteria.

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Alexander D. BERSHADSKY
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Title

Cytoskeleton-adhesion crosstalk in cell motility and force sensing

Abstract

Initial integrin-mediated cell-matrix adhesions (focal complexes) appear underneath the lamellipodia, in the regions of the "fast" centripetal flow driven by Arp2/3-mediated actin polymerization. Once formed, these adhesions convert the flow behind them into a "slow", myosin II-driven mode. Some focal complexes then turn into elongated focal adhesions (FAs) associated with contractile actomyosin bundles (stress fibers). Myosin II inhibition does not suppress formation of focal complexes but blocks their conversion into mature FAs and further FA growth. Application of external pulling force promotes FA growth even under conditions when myosin II activity is blocked. Thus, individual FAs behave as mechanosensors responding to the application of force by directional assembly. Assembly of FAs is triggered by the small G-protein Rho via activation of two major targets, Rho-associated kinase (ROCK) and the formin homology protein, Dia1. ROCK controls creation of myosin II-driven forces, while Dia1 is involved in the response of FAs to these forces. Expression of the active form of Dia1, allows the external force-induced assembly of mature FAs, even in conditions when Rho is inhibited. Conversely, downregulation of Dia1 by siRNA prevents FA maturation even if Rho is activated. Rho is involved also in formation and maintenance of cadherin-mediated cell-cell junctions known as adherens junctions (AJs). We showed that knockdown of Dia1 in epithelial cells leads to destabilization of AJs. This effect is reversed by rescue with the full-length exogenous Dia1. Finally, we found that Dia1 protein is localized to AJs in a Rho-dependent manner. Thus, function of mDia1 appears to be required for the assembly and maintenance of both cell-matrix and cell-cell adhesions. Dia1 and other formins cap barbed (fast growing) ends of actin filaments, allowing insertion of the new actin monomers. We suggested a novel mechanism of such "leaky" capping based on an assumption of elasticity of the formin/barbed end complex. Our model predicts that formin-mediated actin polymerization should be greatly enhanced by application of external pulling force. Thus, the formin-actin complex might represent an elementary mechanosensing device responding to force by enhancement of actin assembly. Another cytoskeletal system, microtubules, is necessary for the proper turnover of focal adhesions in many cell types. In addition to its role in actin polymerization, Dia1 seems to be involved in formation of links between actin filaments and microtubules affecting microtubule dynamics. Several microtubule-associated proteins cooperate with Dia1 in formation of such links. Since microtubules are known to promote FA disassembly, the Dia1-mediated effect on microtubule dynamics may possibly play a role in the negative feedback loop controlling size and turnover of FAs.

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Title

Adhesive Control of Cell Polarity

Abstract

The molecular role of cell-cell or cell-extracellular matrix (ECM) contacts on the polarity of epithelial cell has been well characterized. How the spatial distribution of extracellular environment affects cell asymmetry is less studied. Micro-patterned substrates imposing cells to spread on various combinations of adhesive and non-adhesive areas have previously been used to control the orientation of cell division [1] and to demonstrate that cells can generate identical tractional force on the substrate but that individual stress fibers are differently spaced depending on the spatial distribution of its adherence contacts [2]. The reproducible effect on overall cell compartmentalization enabled the quantification of the spatial organization of intracellular compartments. Analyzing the organization of individual cells plated on different micropatterns, one can show that ECM distribution can predictably modulate cell asymmetry and polarity axes (3). The growth of MTs appears modulated by the asymmetric composition of the cortex. The respective positions of the nucleus and the centrosome-Golgi apparatus indicate that the internal cell polarity of these non-migrating cells is harmonized with the polarity axis of the adhesive environment. Interestingly the cortical asymmetry did not affect the centrosome positioning at the cell centroid. Thus in addition to ECM molecular composition and mechanical properties, ECM geometry could play a key role in developmental processes.

1- Thery M, Racine V, Pepin A, Piel M, Chen Y, Sibarita JB, Bornens M. The extracellular matrix guides the orientation of the cell division axis. Nat Cell Biol. 2005 Oct;7(10):947-53. Epub 2005 Sep 18.
2- Thery M, Pepin A, Dressaire E, Chen Y, Bornens M. Cell distribution of stress fibres in response to the geometry of the adhesive environment. Cell Motil Cytoskeleton. 2006 Mar 20
3- Manuel Théry, Victor Racine, Matthieu Piel, Anne Pépin, Ariane Dimitrov, Yong Chen, Jean-Baptiste Sibarita, Michel Bornens, *in preparation*

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Françoise BROCHARD – Nicolas BORGHI
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Title

Extrusion of membrane tubes from vesicles and cells

Abstract

Membrane tubes are commonly observed structures in living cells that allow important biological functions. When the membrane of the cell or its organelles is subjected to a local force normal to its surface, it deforms to make a thin tube. Such a phenomenon is reproducible on the artificial membranes of giant vesicles.
We use a hydrodynamic flow technique to extract tubes from tethered giant vesicles and cells.
A giant vesicle or a cell is locally stuck at the tip of a micro-needle and introduced in a micro-channel. When the viscous drag of the flow is high enough, the giant vesicle or the cell is carried away while a thin membrane tube anchored at the tip of the needle is extruded from the moving vesicle or cell body.
For giant vesicles, the dynamics of extraction and retraction are governed by the lipid bilayer elasticity. We investigated the effect of membrane permeabilizing molecules.
Using this technique on the human red blood cells, we show that extraction and retraction dynamics are governed by membrane-cytoskeleton interactions, which can be modulated by intracellular ATP. Membrane tube extraction from cells involves the detachment of the bilayer from the cortical cytoskeleton, which is supported by our theoretical model.
We now work on a more complex eukaryotic cell type, on which we can control membrane-cytoskeleton interactions and cytoskeleton mechanical properties with mutant adhesion proteins and specific drugs.
Eventually, we aim at applying this technique on many cells in parallel so that extraction of membrane tubes could be used to detect pathological cells from a tissue sample on the basis of their altered mechanical properties.

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Michael E. CATES
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Title

Nonequilibrium Steady States in Sheared Binary Fluids

Abstract

Nonequilibrium systems include two important classes: those that are evolving towards Boltzmann equilibrium (e.g., by phase separation following a temperature quench), and those that are maintained in nonequilibrium by continuous driving (such as a shear flow). Of surprising subtlety are systems combining both features -- such as a binary fluid undergoing phase separation in the presence of shear. I will present recent lattice Boltzmann simulations for such a system in 2D [1]. Contrary to some theoretical scenarios which predict indefinite coarsening in this situation, we find the first clear evidence of saturation to a nonequilibrium steady state with finite (system-size independent) correlation lengths. Prospects for gaining such evidence in the 3D case, and for using lattice Boltzmann to address other nonequilibrium problems such as active suspensions, will be briefly surveyed.

[1] P. Stansell et al, Phys. Rev. Lett. 96, 085701 (2006)

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Itai COHEN
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Title

Using Confocal Microscopy to Investigate Yielding in Colloidal Crystals

Abstract

Packing constraints play a crucial role in determining the structures formed by a colloidal suspension in thermodynamic equilibrium. However, many technological uses of colloidal suspensions entail application of large strains that drive the suspension out of equilibrium and significantly modify its structure. In such flows, the complex interplay between shear induced stresses and particle packing that leads to structure formation is very poorly understood. To investigate this interplay, we have built a shear cell that can be loaded onto a confocal microscope thus allowing us to image the 3-D microstructure of a dense colloidal suspension when it is subjected to an imposed strain. In this talk, I will describe a range of striking phenomena that are observed in strained colloidal crystals. I will show that at low strain rates such crystals form dislocations akin to those observed in thin atomic crystalline films. By studying such defects in colloidal systems we gain access to the detailed dynamics characterizing the defect motion and leading to the ultimate dislocation distribution in the material. At higher strain rates, the viscous stresses induce a different mechanism for stress relaxation. In this regime the crystal layers separate and form sheets that flow over each other. At high enough strains, these sheets segregate into shear bands characterized by different material properties. Finally, I will describe how these flows change when the crystals are sheared in gaps containing less than 10 particle layers.

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and Laboratoire de Physique Statistique, ENS, Paris, France

Title

Wave-particle duality at a macroscopic scale?

Abstract

We will describe a new experiment in which, at a macroscopic scale, a particle and a wave are strongly coupled together. The experiment relies on the fact that drops can bounce on the surface of a bath of the same fluid if the bath oscillates vertically(1). With small drops and a large enough forcing this bouncing can be sustained indefinitely. This phenomenon occurs far from the threshold of the Faraday instability where the fluid surface becomes unstable and forms standing waves. Immediately below this threshold however, the drop bouncing is a disturbance and generates a local wave-packet of Faraday waves. A self-propulsion effect appears and the drop acquires a translation motion by bouncing on its own wave. A simple theoretical model accounts for the bifurcation leading to the formation of this *walker* in which a drop and its wave-packet are strongly associated.

Several walkers interact, due to the interference of the waves they emit. This interaction is non-local and, depending on distance, is either attractive or repulsive. The collision of two drops can lead to their capture and induces a « binary star » type of orbital motion. We will show that the possible diameters of these orbits form a discrete set(2-4).

A walker can thus be seen as a self-propelled droplet which interacts with its environment (walls, obstacles, other walkers …) through its associated wave. We will report the results of recent experiments on the diffraction and interference of single walkers passing through slits. In these macroscopic scale experiments, we observe phenomena having, surprisingly, some aspects of the wave-particle duality of quantum physics.

(1) Couder Y., Fort E., Gautier C.H. & Boudaoud A., 2005 From bouncing to floating drops: non-coalescence of drops on a fluid bath, Phys. Rev. Lett. 94, 177801
(2) Couder Y., Protière S., Fort E. & Boudaoud A., 2005, Dynamical phenomena: Walking and orbiting droplets, Nature 437, 208.
(3) Protière S., Couder Y., Fort E. & Boudaoud A., 2005, The self-organization of capillary waves sources, J. Phys.: Condens. Matter. 17 S3529-S3535
(4) Protière, S., Boudaoud, A. & Couder, Y., A particle-wave association on a fluid iinterface, to appear in J. Fluid Mech. (May 2006)

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Pierre Gilles DE GENNES
Institute Curie, Physique et Chimie
Paris, France

Title

Some thoughts on friction

Abstract

This presentation starts by a review of solid friction. It then discusses two examples of low friction: diamond films and the graphite/graphite incommensurate contacts.

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Thomas <u>DUKE</u>
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<u>Title</u>

A cochlear travelling wave driven by oscillatory hair cells

<u>Abstract</u>

Recent experiments have shown that sensory hair bundles in the inner ear of non-mammalian vertebrates oscillate spontaneously. Theoretical arguments indicate that their sensitivity to weak periodic stimuli is greatly enhanced when they are poised at the threshold of the oscillatory instability. The mammalian cochlea is more sophisticated, in that the sensory cells are supported on a flexible membrane; as a consequence, their motion is coupled through the fluid. I will discuss a model in which oscillatory hair cells respond to the pressure in the fluid and drive the movement of the basilar membrane, thereby producing a travelling wave. The nonlinear properties of the wave permit energy of a particular frequency to be transported to a specific location in the cochlea and to be absorbed in a very localized region.

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Ramin GOLESTANIAN
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Title

Designing molecular swimmers

Abstract

In light of the development of nano-science and technology in aqueous environment, the need is felt to design machines that could propel themselves in such environments, while they are sufficiently simple that their construction is feasible. In this talk, two classes of such designs will be introduced; one that is based on designer-deformations that can lead to net propulsion, and another whose propulsion is reaction-driven like a jet engine. The feasibility of these designs in terms of how they are made is discussed together with their efficiency.

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Nir <u>GOV</u>
Department of Chemical Physics,
The Weizmann Institute of Science,
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Title

Active thermodynamics of cell membranes: local shapes and global morphology

Abstract

Actin is a small protein that can polymerize in the cell to form long and stiff filaments. This process consumes ATP, and is nucleated and controlled by a variety of other proteins. The cell is using actin polymerization to drive shape deformations of its outer membrane, that are involved in motility and adhesion. We present a dynamical model that accounts for some of the rich variety of membrane structures and motion observed in real cells. This model shows how in the living cells non-equilibrium and equilibrium processes are combined.

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Hans <u>GRULER</u>
Biophysics Department, University of Ulm, Germany

<u>Title</u>

Living Liquid Crystals Formed by Amoeboid Cells

<u>Abstract</u>

General introduction: Classical nematic liquid crystals are formed by elongated molecules having an anisotropic interaction leading to an ordered phase in respect to the molecule orientation. The living nematic liquid crystals are formed by elongated migrating amoeboid cells. The anisotropic cell-cell interaction leads to an ordered state in respect to the cell orientation. The analogies and the differences between the two systems will be discussed.
Biological importance: In cell culture, liquid crystals are formed by elongated, migrating, and interacting amoeboid cells. An apolar nematic liquid crystal is formed by different cell types like human melanocytes (=pigment cells of the skin), human fibroblasts (=connective tissue cells), human osteoblasts (=bone cells), human adipocytes (=fat cells), etc. The nematic state is quite well described by i) a stochastic machine equation responsible for cell orientation and ii) a self-organized extracellular guiding signal, *E*2, which is proportional to the orientational order parameter as well as to the cell density. The investigations were mainly made with melanocytes and fibroblasts. The transition to an isotropic state can be accomplished either by changing the strength of interaction (*e.g.* variation of the cell density) or by influencing the cellular machinery: i) An isotropic gaseous state is observed at low cell density (_ < 110 melanocytes/mm^2 and 250 fibroblasts/mm^2) and a nematic liquid crystal state at higher cell density. ii) The nematic state disappears if the bipolar shaped melanocytes are forced to become e.g. star-like. This can be done by influencing the self-organization of the amoeboid cell by altered genetic information e.g. haploinsufficiency of the tumor suppressor gene neurofibromatosis type 1 (*NF1)* or by altered cellular machinery by molecules like colchicine, staurosporine, etc.

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Ken JACOBSON
Department of Cell & Developmental Biology & Lineberger Comprehensive Cancer Center, University of North Carolina at Chapel Hill, Chapel Hill NC 27599-7090

Title

New Methods to Study Cell Migration

Abstract

We are currently attempting to understand how the basic processes of contractility, protrusion and adhesion are integrated to produce cell migration. This is an intellectually challenging problem that requires new approaches. The overall plan is to develop an in silico model with A. Mogilner for migration and check this model by perturbing these basic processes locally using photomanipulative techniques to see if the experimentally determined changes in locomotion can be accounted for by the model. The feasibility of two types of perturbations has now been demonstrated. Caged actin binding proteins and peptides derived from Focal Adhesion Kinase (FAK) can be uncaged and produce dramatic phenotypes. A complementary loss of function technique, GFP-chromophore-assisted laser inactivation (EGFP-CALI), has been applied locally to several actin binding proteins including EGFP-α-actinin, EGFP-Mena and EGFP-capping protein, again with strong phenotypes.

I will also describe experiments to measure the protrusion force of cell lamellipodia and comparison of the resulting force-velocity and stall force to available theories of protrusion.

Lastly, a recent graph theoretic approach to modeling migration phenomena has been developed by Gabriel Weinreb and Tim Elston. The causal map (C-MAP) is a course-grained biological network tool that permits description of causal interactions between the elements of the network and overall system dynamics. On one hand, the C-MAP is an intermediate between experiments and physical modeling, describing major requisite elements, their interactions and paths of causality propagation. On the other hand, the C-MAP is an independent tool to explore the hierarchical organization of cell and the role of uncertainties in the system. It appears to be a promising easy-to-use technique for cell biologists to systematically probe verbally formulated qualitative hypotheses. We apply the C-MAP to study the phenomenon of contractility oscillations in spreading cells in which microtubules have been depolymerized.

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Josef A. KÄS
Fakultät für Physik, Universität Leipzig, Germany

Title

Intracellular Molecular Machines Formed by Polymeric Films and Active Nanoelements

Abstract

The cytoskeleton, a compound of highly dynamic polymers and active nano elements inside biological cells, mechanically senses a cell's environment and generates cellular forces sufficiently strong to push rigid AFM-cantilevers out of the way. These forces are generated in the lamellipodium – which can be considered a thin polymeric film – by molecular motor-based nano-muscles, and by polymerization through mechanisms similar to Feynman's hypothetical thermal ratchet. The lamellipodium functions as an independent functional unit, even when separated from the cell. The active polymer networks as basic element of the lamellipodium are described by a new type of polymer physics since nano-sized molecular motors overcome the inherently slow, often glass-like Brownian polymer dynamics resulting in novel self-organization and rapid switching through dynamical instabilities. Light has been used to observe cells since Leeuwenhoek's times; however, we use the forces caused by light described by Maxwell's surface tensor to feel the cytoskeleton. The optical stretcher exploits the nonlinear, thus amplified response of a cell's mechanical strength to small changes between different cytoskeletal proteomic compositions as a high precision cell marker that uniquely characterizes different cell types. Consequentially, the optical stretcher detects tumors and their stages with accuracy unparalleled by molecular biology approaches. This precision allows us to isolate adult stem cells for regenerative medicine without contamination through molecular markers. In addition to probing cytoskeletal structure, optical gradient forces can also influence lamellipodial activity allowing us to manipulate neuronal growth. The specific opto-molecular interactions are complex since cells, which cannot modulate diffusion by the parameters found in the Einstein equation (temperature, viscosity, molecular size), exhibit rich multifaceted behavior including ballistic transport and anomalous diffusion, which can be probed by the use of nanoparticles as markers.

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Karsten KRUSE
Max-Planck Institute for Physics of Complex Systems
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Title

Muscle oscillations and a simple swimmer

Abstract

Ensembles of molecular motors can present spontaneous oscillations whencoupled to an elastic element. Such oscillations are thought to drive the beating of flagella and cilia and have been observed in muscle fibers. In this presentation, the latter phenomenon is discussed. The starting point is a simplified description of sarcomeres, which are the elementary force generating units of skeletal muscle. It is shown that a single sarcomere can oscillate spontaneously and that rigidly coupling several sarcomeres in a chain leads to a number of different synchronized states. A continuum wave equation is derived, that describes the dynamics of such a chain on length scales that are large compared to a single sarcomere. Finally, a simple self-organized swimmer based on spontaneous sarcomere oscillations is introduced and analyzed.

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Jonghoon LEE & Anthony J.C. LADD
Chemical Engineering Department, University of
Florida, Gainesville, Florida 32611-6005, U.S.A.

Title

Axial Segregation of a Settling Suspension in a Rotating Cylinder

Abstract

A suspension of non-neutrally buoyant particles, contained in a horizontal cylinder, can be unstable to axial perturbations in concentration if the cylinder is rotated at an appropriate angular frequency. A highly regular pattern of particle density and fluid flow coexist in a non-equilibrium stationary state. The density profile along the cylinder axis is roughly sinusoidal, with a well-defined wavelength equal to the cylinder diameter and a magnitude of approximately 30% of the average number density. Similar patterns were observed in laboratory experiments under similar conditions (Matsen et al. Phys. Rev. E., 67:050301, 2003). We have used numerical simulations within the Stokes-flow approximation to investigate the mechanism underlying axial band formation. Our results show that bands develop from an inhomogeneous particle distribution in the radial plane, which is itself driven by the competition between gravity and the viscous drag of the rotating fluid. We have discovered that the mean angular velocity of the particles is an order parameter, which distinguishes between a low-frequency segregated phase and a high-frequency dispersed phase, where the particles fill the whole volume uniformly. The order parameter is a function of a single dimensionless frequency, which shows that a characteristic length is the mean interparticle separation. As the rotational frequency increases, the particle distribution becomes more homogeneous, and the band structure disappears. Hydrodynamic diffusion stabilizes the suspension against centrifugal forces, allowing for a uniformly dispersed phase that can be used to grow three-dimensional cell cultures in an artificial microgravity environment.

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T. LIVERPOOL
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Title

Rheology of Active Filament Solutions

Abstract

We study the dynamics of an entangled solution of polar semiflexible filaments coupled by molecular motors which generate relative motion of the filaments. We derive hydrodynamic equations for coarse-grained order parameters from a microscopic model of the filament-motor interactions. Using these equations we investigate the mechanical properties in different homogeneous statesas a function of motor and filament concentration. We consider the response of the filament/motor mixture to applied shear deformation in the isotropic phase, non-equilibrium polarized and nematic states.

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Adriaan A. LOUIS
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Title

Hydrodynamic interactions and Brownian forces in colloidal suspensions: Coarse-graining over time and length-scales

Abstract

We describe in detail how to implement a coarse-grained hybrid Molecular Dynamics and Stochastic Rotation Dynamics simulation technique that captures the combined effects of Brownian and hydrodynamic forces in colloidal suspensions. The importance of carefully tuning the simulation parameters to correctly resolve the multiple time and length-scales of this problem is emphasised[1].

Applications to be discussed include: The effect of hydrodynamics and Brownian fluctuations on percolation and aggregation, the sedimentation of colloidal particles, dynamic lane formation in driven suspensions, and the direct simulation of a microfluidic nano-pump.

[1] Hydrodynamic interactions and Brownian forces in colloidal suspensions: Coarse-graining over time and length-scales, J.T. Padding and A.A. Louis, cond-mat/0603391

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F.C. MacKINTOSH
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Amsterdam The Netherlands

Title

Active and passive cytoskeletal networks: prestress, active stiffening, and non-equilibrium dynamics

Abstract

Networks of filamentous proteins play a crucial role in cell mechanics. These cytoskeletal networks, together with various crosslinking and other associated proteins largely determine the (visco)elastic response of cells. Cytoskeletal biopolymers have also provided new insights into basic aspects of polymer physics. In contrast to common flexible polymer materials, the response of these networks is highly non-linear, and their rheological properties can be tuned with small changes in density or local network connectivity. In the cell, these systems are also out of equilibrium in a way unique to biology: their rheological properties can reflect internal active force generation by molecular motors. We describe recent theoretical and experimental results on an in vitro model system, involving crosslinked cytoskeletal filaments and crosslinks, that demonstrates non-significant stiffening and non-equilibrium fluctuations due to motor activity.

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Syracuse University, Physics Department
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Title

Ordered states and instabilities in active polymer solutions

Abstract

In this talk I will describe the large-scale collective behavior of solutions of polar biofilaments and motor proteins. We start from a Smoluchowski equation for rigid filaments in solutions, where the motor proteins are described as active crosslinks capable of exchanging forces and torques among the filaments. The large-scale properties of the system are described in terms of continuum equations for filament and motor densities, polarization and alignment tensor obtained by coarse-graining the Smoluchovski equation. The possible homogeneous and inhomogeneous states of the systems are obtained as stable solutions of the dynamical equations and are characterized in terms of experimentally accessible parameters. The presence of crosslinks enhances alignment, lowering the density of the isotropic to nematic transition. In addition, polar crosslinks allow for a homogeneous polarized state. Each state can become unstable at high filament and motor density due to filament bundling. We will make contact with work by other authors and show that our model allows for an estimate of the various parameters in the hydrodynamic equations in terms of physical properties of the motor proteins.

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Title

Active segregation of lipid tethered proteins in the membranes of living cells

Abstract

GPI-anchored proteins are lipid tethered proteins attached to the exoplasmic face of the cell surface. At the cell surface they form clusters which are composed of at most four molecules and accommodate diverse GPI-anchored protein species. In conjunction with an analysis of the statistical distribution of the clusters, our observations suggest an active mechanism for lipid-dependent clustering of GPI-anchored proteins. These nanoclusters appear to be in turn spatially clustered in an actin-dependent manner. Concurrently, nanoclusters of GPI-anchored proteins are sorted into a dynamin-independent pinocytic pathway that also is regulated by both lipid composition and actin polymerization. These studies support a picture wherein larger scale structures are induced from pre-existing nano-scale lipid dependent structures, maintained by actin. These studies argue for active segregation of lipid components into functional domains.

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Workshop on Driven States in Soft and Biological Matter
18 - 28 April 2006 (ref. smr. 1746)

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Title

Interphase microtubule organization in fission yeast.

Abstract

The fission yeast Schizosaccharomyces pombe maintains a cylindrical shape by alternating polarized growth at the cell ends with divisions in the middle. The localized growth is established during interphase by four to six bundles of microtubules that deposit growth factors specifically at cell ends. The bundles are anti-parallel and align along the main cell axis. Furthermore, they are attached to the nucleus, and position it near the cell-center. I will present two models to study this organization: a model of how bundles are organized by the action of molecular motors, and a model of how nucleus and microtubules position within the cell volume. I will conclude by showing how these models suggest that a proper shape is sufficient to establish cell polarity.

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Title

Instabilities and Chaotic Behaviour in Shear Banding Complex Fluids

Abstract

A variety of complex fluids, such as liquid crystals, polymers, and surfactant solutions (lamellae or cylindrical micelles), are easily perturbed by shear flow and exhibit apparent "phase transitions" and complex nonlinear dynamics. "Shear banding", or separation of material into bands of different apparent viscosities, has been reliably observed in wormlike micelles and many other systems. Despite a general one dimensional (1D) theory that predicts stable bands, recent experiments suggest that the generic situation is dynamic, rather than steady bands. After an overview I will present recent calculations to address the possibility of rheo-chaos, and two dimensional calculations to verify or refute the previously found 1D solutions.

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Title

Modelling suspensions of swimming micro-organisms (Modelling populations of swimming micro-organisms)

Abstract

Bioconvection patterns are observed in shallow suspensions of randomly, but on average upwardly, swimming micro-organisms which are a little denser than water. The basic mechanism is analogous to that of Rayleigh-Benard convection, in which an overturning instability develops when the upper regions of fluid become denser than the lower regions. The reason for the upswimming however depends on the species of micro-organism: certain biflagellate algae are bottom-heavy, and therefore experience a gravitational torque when they are not vertical; certain oxytactic bacteria swim up oxygen gradients that they generate by their consumption of oxygen. Rational continuum models can be formulated and analysed in each of these cases, as long as the cell volume fraction n is low enough for hydrodynamic or other cell-cell interactions to be neglected ($n \leq 0.1\%$). The key mathematical step is the calculation of the probability density function for the cells' swimming velocity from a suitable Fokker-Planck equation, when that is justifiable. Both examples will be discussed from this point of view.

Another sort of pattern-formation ("whorls and jets") is observed in very concentrated, very shallow cultures of swimming bacteria on agar plates. Here cell-cell interactions are crucial, but it is not clear how to derive an appropriate macroscopic model that is consistent with the laws of mechanics at the cellular level. A recent attempt (J Lega & T Passot, Phys Rev E, 67, 2003) succeeds in generating patterns on the correct scale, but appears not to be rationally justified. Here we examine the deterministic swimming of model organisms which interact hydrodynamically but do not exhibit

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intrinsic randomness except in their initial positions and orientations. A micro-organism is modelled as a squirming, inertia-free sphere with prescribed tangential surface velocity. Pairwise interactions have been computed using the boundary element method, supplemented by lubrication theory, and the results stored in a database. The movement of 27 identical squirmers is computed by the Stokesian Dynamics method, with the help of the database of interactions (the restriction to pairwise interactions requires that the suspension be semi-dilute, with particle volume fraction less than about 0.1). It is found that the spreading in three dimensions is correctly described as a diffusive process a sufficiently long time after the motion is initiated, although all cell movements are deterministic. The effective translational and rotational diffusivities depend strongly on volume fraction and mode of squirming. However, in two dimensions the squirmers show a definite tendency to aggregation.

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Title

Cellular Sensing of Force and Geometry: Local Force-dependent Unfolding of p130Cas Acts Globally Through Oncogenes.

Abstract

The shape and behavior of mammalian cells is defined by an interplay between extracellular signals and the cellular responses. Although the chemical nature of the external signals is important, it is clear that physical aspects of the external environment are equally important. In particular, the molecular-level geometry and forces have major effects on cell behavior (Vogel and Sheetz, Nature Rev. Mol. Cell Biol., April, 2006). Of particular importance is the rigidity response since cancerous cells can often grow on soft agar, i.e. oncogenes are involved in defining cell mechanics (reviewed in Giannone and Sheetz, Trends Cell Biol., April, 2006). Thus, a critical component for cancer is the ability to override the requirement for force production and rigidity response. For most mammalian cells there are relatively few types of motility that are evident from quantitative analyses of rapidly spreading fibroblasts (Dubin-Thaler et al., Biophys. J. 86:1794-1806, 2004). One motile phase that we have studied extensively involves periodic contractions (24 s period) in local regions of the leading edge of the cell (Giannone et al., Cell, 116:431-443, 2004). The periodic signal is carried radially from the cell edge toward the center and is part of a general mechanism for rigidity-directed movement and pathfinding. Another motile phase involves the movement of individual collagen fibers in a hand-over-hand fashion (Meshel et al., Nature Cell Biol. 7:157-164, 2005) where the geometry of the fiber is being sensed. Rigidity and geometry responses in these systems are dependent upon the cytoskeleton and force-dependent tyrosine phosphorylation through oncogenes (Sawada and Sheetz, J Cell Biol. 156:609-15, 2002; Tamada et al., Developmental Cell, 7:706-718, 2004) that appears to involve unfolding of cytoplasmic kinase substrates, particularly p130Cas (Sawada et al.). Recent studies indicate that the cell rigidity response requires RPTPa and occurs preferentially at the leading edges of moving cells through forces of 10-20 pN generated by displacements of 50-100 nm (Jiang et al., Biophys J. 90:1804, 2006). The mechanism of rigidity response involves recruitment of Fyn kinase in a palmitoylation-dependent process and the phosphorylation of p130Cas at the leading edge. A displacement mechanism for the rigidity response is postulated. We will discuss how cells organize motility tools in motile phases (Döbereiner et al., Phys. Rev. Letters. 93:108105-1-4, 2004) in a dialogue with the environment to define cell morphology and behavior over time.

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Title

Collective Behavior in Addressable Excitable Media

Abstract

We discuss two topics of collective behavior in the context of excitable media models, swarming behavior and spatiotemporal networks. Studies of controlling reaction-diffusion waves with realistic excitability potentials are described. We also describe a study of dynamical networks in the photosensitive Belousov-Zhabotinsky reaction. We model local nearest-neighbor interactions by the spread of reaction-diffusion waves, while nonlocal excitations are described by nondiffusive jumps along shortcuts defined in the medium.

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Title

Routes to Rheochaos: Recent Experiments

Abstract

We show experimentally that the route to chaos is via intermittency in a shear-thinning wormlike micellar system of Cetyltrimethylammonium Tosylate (CTAT), where the strength of flow- concentration coupling is tuned by the addition of salt sodium chloride. A Poincar'e first return map of the time series and the probability distribution of laminar lengths between burst events shows that our data is consistent with type-II intermittency. The coupling of flow to concentration fluctuations is evidenced by the “Butterfly” intensity pattern in Small Angle Light Scattering (SALS) measurements performed simultaneously with the rheological measurements. The scattered depolarised intensity in SALS, sensitive to orientational order fluctuations, shows the same time-dependence (like intermittency) as that of shear stress.

Most interestingly, we see different routes to chaos depending on whether the control variable is stress or shear rate. We will also show our very recent unpublished results on spatio-temporal aspects of the problem.

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Title

Active and nonlinear microrheology of complex materials

Abstract

While materials are most commonly thought of as solids, liquids, or gasses, a tremendous variety of everyday materials (biological materials, consumer care products, foods, etc.) elude such easy classification. Rather, they fall somewhere in between -- e.g. solids on short time scales and fluids on long time scales. Over many decades, techniques in rheology have been developed to study how such materials deform and flow. Conventional rheology is 'macroscopic', in the sense that it requires milliliter quantities for analysis. Many materials, however, would be too difficult, too expensive, or impossible to procure in the amounts required for such (macro-) rheometry. In the past decade, "microrheology" has been developed to study such materials. Rather than externally forcing a macroscopic quantity of the material, small colloidal beads are introduced and driven into (Brownian) motion by thermal forces. Because the material remains in (or close to) equilibrium, the (frequency-dependent) linear-response properties of the material can be obtained from the fluctuating probe motion using the fluctuation-dissipation theorem. This, however, suggests another limit to microrheology -- nonlinear material properties (shear thickening or thinning, yield stresses, and so on) can not be obtained using conventional techniques. Here we will discuss recent experiments in which the colloidal probe is actively driven through the material in order to probe its nonlinear response. We will address various theoretical issues in such studies -- most crucially, what exactly is being measured, and how might these measurements be interpreted to give the material information one desires?

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Title

Flows and instabilities in active gels: applications to cytoskeleton dynamics

Abstract

Molecular biology provides today an extremely detailed description of the components of living cells. However, the physical properties of the cell cytoskeleton, such as its mechanical properties, are still poorly understood. The complexity of the microscopic processes involved in cytoskeleton dynamics is such that it is necessary to introduce effective coarse-grained models to study its macroscopic properties. Here we describe the cytoskeleton as an out-of-equilibrium viscoelastic polar gel. We show in particular that the "activity" of the gel, induced by the molecular motors consuming ATP, can give rise to spontaneous flows in the gel, and trigger different kinds of instabilities. We give a generic phase diagram of thin films of active gels, which is in good qualitative agreement with in vivo and in vitro observations.

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Title

Self-Organized Regular Motion of a Droplet

Abstract

We will report the experimental results on the emergence of self-controlled vectorial motion of a droplet, powered either by continuous photon flux or by chemical potential gradient. The spontaneous motion of the droplet is considered as a representation of spatio-temporal structure under far-from-equilibrium conditions. It is found that various characteristic modes on the spontaneous motion are generated. Switching between the modes will be discussed in terms of phenomenological nonlinear differential equations by incorporating the effect of the flexible, soft boundary of the droplet.

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Active motion driven by laser

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