DOWNLOAD PDF GRANULAR AND COMPLEX MATERIALS

Chapter 1 : Granular And Complex Materials - UCL Discovery

A granular material is a collection of distinct macroscopic particles, such as sand in an hourglass or peanuts in a container. The evolution of the particles follows Newton's equations, with repulsive forces between particles that are non-zero only when there is a contact between particles.

What causes an avalanche of rocks or snow? We may think of these systems as a collection of grains. The behavior of a single grain is easily understood, but the properties of a collection of grains is very complex. Granular materials when poured or shaken display a surprising range of collective behavior such as convection, size separation and pattern formation. Granular materials are important constituents in many industrial processes and geophysical phenomena. However, no fundamental statistical theory is currently available to describe their properties. A major factor is the lack of quantitative experiments that can be used to develop models. Therefore, we have performed a series of experiments to investigate their properties in my laboratory. Some recent examples and their motivation are discussed below. Correlations and distributions We investigated the velocity distributions of steel spheres rolling on a tilted rectangular two dimensional surface using high speed imaging imaging. This is one of the simplest model systems to investigate the application of hydrodynamic approaches to granular matter. The particles are excited by periodic forcing of one of the side walls. We observe strongly non-Gaussian velocity component distributions even in the dilute regime Kudrolli unlike what has been assumed in developing theory of rapid granular flow. The particle velocities are observed to be correlated over large distances comparable to the system size Blair We implemented long time particle tracking of all the particles in the system. This enabled us to obtain collision properties including the inelasticity parameter. The path length and collision time distributions of the particles were found to deviate from formulas calculated from the kinetic theory of elastic gases Blair We propose a new function for the distributions which has not yet been explained by theory. The radial correlation function was measured and found to deviate from the Carnahan and Starling formula normally used in theory. These results form the context for new experiments that we are performing on the equation of state of excited granular matter. Magnetized granular materials We studied the effects of long range interactions on the phases observed in cohesive granular materials. Our system consists of magnetized steel particles inside a container which is vibrated vertically Blair , At high vibration amplitudes, a gas of magnetized particles is observed with velocity distributions similar to non-magnetized particles. Below a transition temperature compact clusters are observed to form and coexist with single particles. The cluster growth rate is consistent with a classical nucleation process. However, the temperature of the particles in the clusters is significantly lower than the surrounding gas, indicating a breakdown of equipartition. If the system is quenched to low temperatures, a meta-stable network of connected chains self-assemble due to the anisotropic nature of magnetic interactions between particles [see figure above]. This is a rich model system which can be used to study complex cohesive granular materials. Dynamics of anisotropic grains We investigated the effect of anisotropy of the constituent particles on the packing and dynamics of granular matter. These experiments were inspired by Seth Fraden. An important question is whether orientational order due to the principle of entropy maximization observed in anisotropic thermal systems carries over to dissipative granular systems. We find that not only do the particles self-organize to form ordered domains from an initial random state but also observe novel motion [see movie]. Vortex patterns are observed when a container filled with rods is vertically vibrated Blair Above a critical packing fraction, moving domains of nearly vertical rods spontaneously form and coexist with horizontal rods. We show that the motion is generated due to the inclination of the rods by doing experiments with a row of rods in an annulus. In collaboration with L. This is a novel example of a granular rachet formed due to spontaneous symmetry breaking. More recently we have studying the dynamics of a single dimer on an osciallted plate. This is a simple generalization of the classic bouncing ball paradigm for period doubling and transition to chaos. We observe several novel modes including a drift mode in which uphill drift motion can be induced by suitable choice of parameters Dorbolo Diffusion and surface flow instabilities inside silos We examined the gravity driven flow of granular materials inside a silo in collaboration with M. By tracking individual particles over long periods of time we showed that while the mean flow was reasonably described by kinematic and diffusing void models, the actual amount of particle diffusion was very small Choi A sub-ballistic to diffusive crossover was observed. A new model which takes into account the observed correlations has been developed and is being currently tested. Effect of liquids on the cohesive and segregation properties of granular matter We studied the effect of adding small amounts of liquids to granular matter. This is a topic in which little quantitative work has been done even though humidity or liquids are almost always present in natural situations where granular matter occurs. Two different experimental setups were used. First, our experiments were conducted with mixtures poured into a quasi-two dimensional silo which allows visualization through the transparent side walls. Our data for the increase in the angle of repose and subsequent saturation appears to be inconsistent with some of the models of wet granular matter. Our experiments showed the importance of viscosity of the liquid in determining the angle of repose of the pile formed after pouring the granular mixture Samadani We also reported one of the first systematic studies of segregation transition of bidisperse granular mixtures in the presence of liquids Samadani Then, the maximum angle of stability of a cohesive pile was investigated using a rotating drum apparatus to understand the discrepancies noted in previous studies. We first showed the effect of the side walls by varying the width of the drum. The maximum angle of stability was then measured in the limit where side walls are unimportant. We developed a new liquid bridge model which takes into account the nature of the grain contacts and the cohesive force due to liquid bridges to show the grain size, system size, and surface tension behavior Nowak In this model, the friction between particles is considered less important compared to geometric stability of the particles. The experimental data is in excellent agreement with the prediction of our model. See the publications home page for cited references.

Chapter 2 : Granular Materials

The paper deals with numerical investigations of size effects in granular bodies during quasi-static plane strain compression under plane strain conditions and constant lateral pressure. For a simulation of the mechanical behaviour of a cohesionless granular material during a monotonous deformation.

International Focus Workshop 8 - 10 July The study of granular and other particulate networks is one of the most prominent areas of condensed-matter physics. However, progress is stymied by sparse interactions between individuals trained in the disparate network-based approaches that are relevant for granular media from subjects such as statistical mechanics, network clustering, multilayer networks, algebraic topology, and more and those that are trained in materials physics. From new trainees to seasoned investigators, individuals seeking to contribute to this field are required to find and parse a diverse and scattered literature from day one. The goal of our focus workshop is to close this gap. Why use network science? The arrangements of particles and forces in granular materials and particulate matter have a complex organization on multiple spatial scales that range from local structures to mesoscale and system-wide ones. This multiscale organization can affect how a material responds or reconfigures when exposed to external perturbations or loading. The theoretical study of particle-level, force-chain, domain, and bulk properties requires the development and application of appropriate mathematical, statistical, physical, and computational frameworks. Traditionally, granular materials have been investigated using particulate or continuum models, each of which tends to be implicitly agnostic to multiscale organization. Recently, tools from network science have emerged as powerful approaches for probing and characterizing heterogeneous architectures in complex systems, and a diverse set of methods have yielded fascinating insights into granular materials. Network science offers methods for quantitatively probing and analyzing large, interacting systems whose associated networks have heterogeneous patterns that defy explanations using regular or lattice-like interactions. Because granular materials have heterogeneities on many length and time scales, it is challenging to model their material properties and responses. The ability of network science to provide both qualitative and quantitative descriptions of the organization and dynamics of granular materials is very promising. Our purpose is to bring together physicists, mathematicians, and materials scientists who study these problems. The workshop will open with presentations from experimentalists presenting data collected using the newest techniques available in the field. We will then catalyze new uses of these data with talks from experts in the theory of networks, the development of tools to characterize networks, the application of network tools to studies of granular materials, and the development of physically-informed network-based models and statistical techniques to granular media. We will place particular emphasis on how networks can be used to quantify heterogeneous organization in granular materials and to understand how these systems evolve when exposed to external perturbations. We seek a crystallization of particularly fundamental open questions and hope that participants will leave inspired to explore the applications of new techniques to new problems. Key questions What are the key characteristics of the spatial and temporal patterns of force transmission in granular and other particulate materials? What are the most appropriate tools from network analysis and other areas of mathematics , either existing or to be developed, to describe the dynamics of granular materials? How do we predict which parts of a granular system will fail using these tools, and how do we design and engineer materials with desired properties?

Chapter 3 : Physics of Granular Materials

The science of complex materials continues to engage researchers from a vast range of disciplines, including physics, mathematics, computational science, and virtually all domains of engineering.

A View from Emerging Technology from the arXiv How Self-Assembling Granular Materials Are Changing the Future of Architecture Architects are toying with exotic new materials that can be poured into place and yet form complex structures October 30, Architecture is a conservative discipline, not least because of the exacting standards of stability and safety that all human-made structures must adhere to. The forces acting on and within any structure must be carefully calculated and the design modified accordingly. Little can be left to chance. This kind of building will rely on new kinds of granular materials that when tipped into place, bind together in ways that provide structural stability. In this way, walls, columns and even domes could be poured into place, forming complex but stable structures. These guys say that the first aleatory structures are already being built and that the approach is introducing new ways to think about architecture and design in general. Human have used granular materials such as stones, sand, or earth to build structures for thousands of years. Even today, the technique is common for constructing dams, harbor breakwaters, and gravel beds for railways. These structures benefit from the special properties of granular materialsâ€”their porous nature that allows quick drainage and the fact that they can be poured into place quickly and at low cost. More interesting is the way they bear loads. Conventional structures require specially designed columns or arches. But granular materials rely on force chains between adjacent particles inside the materials that are set up when the material becomes jammed. At the same time, the material can flow when the jam is released. There is downside though. And that also limits the applications. Much of the properties of granular materials are determined by the shape of the particles from which they are made. This is roughly spherical in many cases. But in recent years, materials scientists have begun to experiment with particles with more exotic shapes, such as 3-D star shapes, X shapes, hook shapes, and others. When poured, these more easily jam and form stable structures. Traditionally, architects have started with the smallest structural components such as columns, arches, walls, and so on and joined them together to form larger structures such as bridges, houses, and skyscrapers. But the properties of these new granular materials turn this approach on its head. With this stuff, architects can think about the overall form and then work out how it can be achieved by pouring the granular material into place. One approach is to pour the material into an air-tight fabric container that can be vacuum packed. This generates the pressure that causes the material to jam into more or less any desired shape. A more ambitious goal is to come up with the overall structure and then work backward to determine the shape of the particles that would produce it when poured. These granules could then be 3-D printed and poured into place, where they would self-assemble or be assembled using a robot. That will have a profound effect on the process of design.

Chapter 4 : Granular material - Wikipedia

At the meeting, international experts from 21 different countries gathered together to debate and discuss the latest advances in the experimental, computational and mathematical analysis of granular materials and other related complex materials such as foams, porous media and cellular solids.

Our papers on granular and amorphous materials Back to research page Granular Materials A granular material is a collection of distinct macroscopic particles, such as sand in an hourglass or peanuts in a container. Although granular materials are very simple to describe they exhibit a tremendous amount of complex behavior, much of which has not yet been satisfactorily explained. They behave differently than solids, liquids, and gases which has led many to characterize granular materials as a new form of matter. A granular material on an incline plane, from simulations by Silbert and coworkers For example, if a granular material is heaped on an inclined plane, then the large scale state of the system depends on the angle of the plane. For large angles the granular material flows like a non-Newtonian liquid. For small angles the granular material will behave like a solid and remain stationary. The value of the critical angle between these phases depends on the preparation history, and the transition between the phases is a manifestation of the glass transition. As you can see, there is a lot of interesting and complex physics to be understood by studying just the large scale properties of a granular material in such a simple arrangement. As the composition becomes more complicated, the behavior becomes even richer. From a small scale point of view, the characteristics that make granular materials interesting are inelastic collisions and the unimportance of temperature. Because collisions between particles are inelastic then the energy of a granular material is a dynamic quantity, and because the particles that make up a granular materials are macroscopic then temperature does not produce significant motion. Ultimately we would like to describe the properties of a granular material using statistical arguments, but since there is no well defined energy or temperature then conventional equilibrium statistical mechanics does not apply. A full understanding of granular materials will require an extension of statistical mechanics, which is of great fundamental interest. Constitutive laws for granular flows A constitutive relation is an equation that relates the stress in a material to other known variables. The common constitutive relation in fluid dynamics sets the stress proportional to the strain rate. In granular materials this constitutive relation does not hold and evidence points to a quadratic relation between stress and strain rate. In our work on granular materials, we concentrate on the 2-dimensional shearing geometry shown in figure 1. The shearing geometry is interesting because what we learn can be applied to studies on friction and earthquakes. In this geometry a shear stress s is applied to the top and bottom of the material and a confining pressure p keeps the material from expanding. If s is large enough, the granular material will begin to move and eventually reach a steady state. These average velocities must be somehow related to the stresses s and p. STZ theory introduces variables that describe the internal, history dependent structure or state of a solid. These variables describe the state of the solid by specifying the number of regions in a dense material that are able to move non-affinely in order to flow. The shear rate can then be written in terms of the state variables. STZ theory is an example of a rate and state law. To test this relation we conduct computer simulations of sheared granular materials. Figure 2 is a movie of one such simulation. After many such simulations we obtain the data points shown in Figure 3. The bottom curve is for a granular material with no friction between particles and the upper curve has some amount of friction between particles. The line drawn through the data points is the prediction from STZ theory. As you can see, the agreement is very good, and we were the first group to accurately predict this flowing constitutive relations for dense granular materials. The constitutive relation in figure 3 only applies to steady state flow. In the transient regime, where all of the variables have non-zero time derivatives, STZ theory makes predictions on their time dependence. These predictions must be understood and tested. STZ theory not only gives information about the flowing state of a granular material, but also makes predictions about how a granular material jams transforms from liquid-like to solid-like behavior. It is very important to understand and test these predictions as well. Many properties of granular materials depend on the distribution of grain radii. Figure 3 was obtained with one distribution and it would be interesting to know how the parameters in the STZ theory depend on the distribution of grain radii. More conceptually, STZ theory is based on the fact that there are regions in a granular material that are able to transform non-affinely. The study of sheared granular materials is closely related to the study of friction in earthquake faults. This relation should be explored further. We hope to undertake these projects soon.

Chapter 5 : Granular and Particulate Networks

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Force chain Chain of transmission of stress forces in a granular media When the average energy of the individual grains is low and the grains are fairly stationary relative to each other, the granular material acts like a solid. In general, stress in a granular solid is not distributed uniformly but is conducted away along so-called force chains which are networks of grains resting on one another. Between these chains are regions of low stress whose grains are shielded for the effects of the grains above by vaulting and arching. Granular gases[edit] If the granular material is driven harder such that contacts between the grains become highly infrequent, the material enters a gaseous state. Correspondingly, one can define a granular temperature equal to the root mean square of grain velocity fluctuations that is analogous to thermodynamic temperature. Unlike conventional gases, granular materials will tend to cluster and clump due to the dissipative nature of the collisions between grains. This clustering has some interesting consequences. For example, if a partially partitioned box of granular materials is vigorously shaken then grains will over time tend to collect in one of the partitions rather than spread evenly into both partitions as would happen in a conventional gas. Jamming transition[edit] Jamming during discharge of granular material is due to arch formation red spheres Granular systems are known to exhibit jamming and undergo a jamming transition which is thought of as a thermodynamic phase transition to a jammed state. Some of the pattern-forming behaviours seen in granular materials are: The un-mixing or segregation of unlike grains under vibration and flow. An example of this is the so-called Brazil nut effect where Brazil nuts rise to the top of a packet of mixed nuts when shaken. The cause of this effect is that when shaken, granular and some other materials move in a circular pattern. The formation of structured surface or bulk patterns in vibrated granular layers. These patterns include but are not limited to stripes, squares and hexagons. These patterns are thought to be formed by fundamental excitations of the surface known as oscillons. The formation of ordered volumetric structures in granular materials is known as Granular Crystallisation, and involves a transition from a random packing of particles to an ordered packing such as hexagonal close-packed or body-centred cubic. This is most commonly observed in granular materials with narrow size distributions and uniform grain morphology. The formation of sand ripples , dunes , and sandsheets Some of the pattern-forming behaviours have been possible to reproduce in computer simulations. Acoustic effects[edit] Sand dunes Some beach sands, such as those of the aptly named Squeaky Beach , exhibit squeaking when walked upon. Some desert dunes are known to exhibit booming during avalanching or when their surface is otherwise disturbed. Granular materials discharged from silos produce loud acoustic emissions in a process known as silo honking. Granulation Granulation is the act or process in which primary powder particles are made to adhere to form larger, multiparticle entities called granules. Modeling of granular materials[edit] Several methods are available for modeling of granular materials. Most of these methods consist of the statistical methods by which various statistical properties, derived from either point data or an image, are extracted and used to generate stochastic models of the granular medium. A recent and comprehensive review of such methods is available in Tahmasebi and other

Chapter 6 : Granular and complex materials - PDF Free Download

The science of complex materials continues to engage researchers from a vast range of disciplines, including physics, mathematics, computational science, and virtually all domains of blog.quintoapp.com volume presents a unique multidisciplinary panorama of the current research in complex materials.

Three types of 2D foams. From left to right: Note the contrast between the Bragg and Smith systems. The three length scales: Typically they are as follows: The properties of general interest include those that are essentially static or can be described quasi-statically, like structure, stability, elasticity, coarsening, quasistatic rheology, light scattering, electrical and thermal resistance. Increasingly, properties that are truly dynamic are addressed, including details of transformations and structural relaxation, rate-dependent rheology, drainage, convective instability, size segregation. Theory is sometimes complicated by the history-dependence of foam structure and hence its properties. However, the statistical properties of the bubble packing, such as the average number of faces per cell, remain the same. Is there a closer correspondence? Should we regard a gas bubble as a frictionless, compressible particle? Durian33 and others have tried to integrate foam theory with granular and atomic systems, by using a single idealised model for all three, as we shall explain below. There may be some. Laboratory equipment can be rudimentary: Besides, many foams are partially transparent, so that some limited observation of their interior is possible. Key physical parameters The key physical parameters describing an ordinary aqueous foam include those that characterize the liquid and its surface: In simple theories this is often the only parameter of interest and hence tends to disappear entirely in simulations. Their role has been studied by physical chemists for a long time but are only now being properly integrated into foam physics. Further basic parameters characterise the foam structure: How can we access quantitatively these structural parameters in practice? We might squash and two-dimensionalise a three-dimensional 3D foam sample between two plates, in order to estimate d. It is also possible to infere to some extent the size distribution in the bulk from what is observable on the sidewalls. As for granular media, the complete structure can also be accessed by tomography techniques see section 5. Remarkably, a lot of physics can be developed in terms of these few variables leaving out surface viscosity and surface elasticity, if possible , after a few simplifying approximations. Most of the basic formulae that roughly capture physical properties can be found in the book of Weaire and Hutzler. Wet and dry foams The value of liquid fraction in a disordered foam can range between 0 corresponding to an ideal polyhedral packing of bubbles and approximately 0.