Fall 2010 COLLOQUIUM SERIES

GRANULAR AND MULTIPHASE FLOWS

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The Granular Science Laboratory

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October 4, 2010
11:30 a.m. – 1:00 p.m.
GITC 3710

Powders Behaving Like Liquids

Equilibrated colloidal suspensions obey the laws of thermodynamics; have osmotic properties, and obey Gibbs phase rule. By contrast, properties of dry colloidal powders, not in a host solvent, but which are fluidized under gravity by mechanical vibrations are not in any real sense thermodynamic. Both common experience and careful experiments, however, demonstrate that fluidized powders can, in certain conditions, be described by quasi-thermodynamic laws. Computer simulations confirm an obedience criterion is the amplitude of vibration should be less than all correlation length for interactions between particles. Then the conditions for the equipartition-of-energy prevail. There follows a definition of quasi-thermodynamic properties of powders as functions of a granular temperature, and a granular pressure. "Thermodynamics" can predict whether excited powders prefer to be separate phases, or mixed. A very simple consideration of the mixing criteria of hard spheres that differ only in size, suggests that all powders will mix if vibrated at a sufficiently small amplitude and characteristic frequency. Consider a two-component powder A+B, then the criterion for the mixing process at equilibrium is that the excess Gibbs free energy of mixing should be negative. Pressure enhances mixing if the volume change is negative, and segregation it is positive. Increase in granular temperature, on the other hand, always favors mixing. Even the most difficult binary powders will mix with sufficient kinetic energy. These ideas have resulted in the discovery of an extraordinary phase behavior of binary powders in acoustic vibrations. The granular temperature is close to uniform, whereas the pressure varies under gravity from zero at the top to the weight of the system at the bottom. The results have been confirmed by computer simulations and tenets of density functional theory also apply to these inhomogeneous systems. There are many potential applications.

Leslie Woodcock was educated in the UK and received his PhD. at the University of London in 1970. Currently, he is a visiting professor in the Center for Molecular and Engineering Thermodynamics at the University of Delaware. He has held academic appointments at the University of Cambridge, University of Amsterdam, University of Bradford and UMIST where he is Emeritus Professor of Chemical Thermodynamics. He has also served as senior research consultant at Wright-Patterson Air Force Laboratory, as a consultant to Unilever and the International Fine Particle Research Institute, a visiting Professor at the University of Singapore, and a guest scientist at the U.S. NIST. Dr. Woodcock is a Fellow of the Royal Society of Chemistry, a founding editor of *Molecular Simulation*, and a recipient of a Max Planck Society Visiting Fellowship. Over his career, he has received wide recognition for his research contributions to understanding the behavior of liquids and complex materials.

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