

Introduction

Colloids are tiny solid particles suspended in a solvent. For our purposes, their size is on the order of $1\ \mu\text{m}$, meaning they undergo Brownian motion yet can be seen using an optical microscope. Thermal motion makes colloidal suspensions thermodynamic systems, and the tools of statistical mechanics, usually reserved for the behavior of molecules, may be applied. Colloids can form crystals, and numerous studies have shown that colloidal crystals are alike to atomic ones in many ways.

This summer, we used colloids to study impurity motion in crystals. Current theory predicts certain impurity behaviors while crystals undergo repeated melting and freezing. However, this technique does not work as predicted for impurities in spherical silicon, an exciting candidate photovoltaic material [1]. We hope to discover empirically how this motion is achieved by watching it in colloids.

Our System

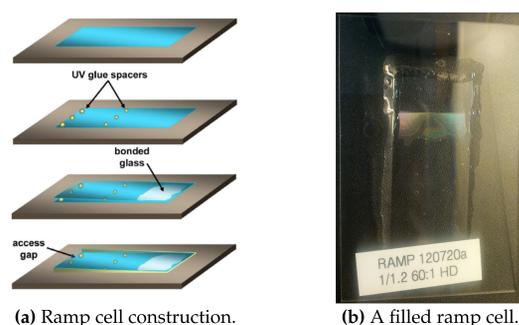


Figure 1: Ramp Cell Information

We study impurity motion in 2D colloidal crystals contained in *ramp cells*, or two glass slides separated by a narrow, wedge-shaped gap. Each ramp cell is filled with a solution of $1\ \mu\text{m}$ and $1.2\ \mu\text{m}$ diameter silica spheres, a size ratio which corresponds to that of impurities in silicon crystals. Since the cell contains a height gradient, a monolayer of particles is formed over some region, which we then image using a light microscope.

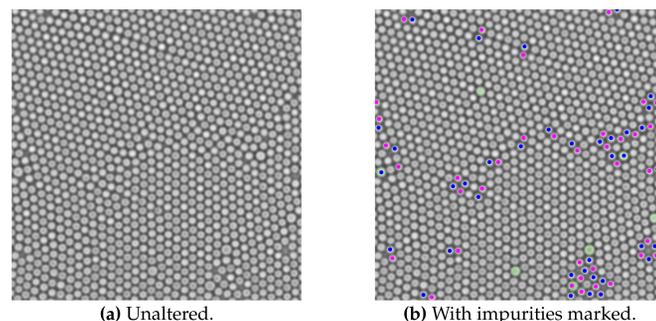


Figure 2: A Colloidal Crystal

The Depletion Interaction

The crystallization of hard spheres is governed by their packing fraction. Unfortunately, it is difficult to change packing fraction once a sample has been made. In order to observe impurities during cycles of melting and freezing, we hope to make use of a tunable interparticle interaction.

The *depletion interaction* is an effective attractive potential between colloidal particles caused by suspending them in a solution of much smaller particles. In such a solution, bringing two large particles together (Fig. 3) excludes smaller ones from a region between them. Because of this, the buffeting from the small particles acts only from the exterior of the particle pair, and an attractive net force results. Depletion can also be described by attempting to maximize the volume available to the small sphere solution, or by applying methods from the density functional theory of fluids [2]. The latter procedure yields very accurate results for depletion, and can also be applied to the liquid state of our system of colloids with impurities.

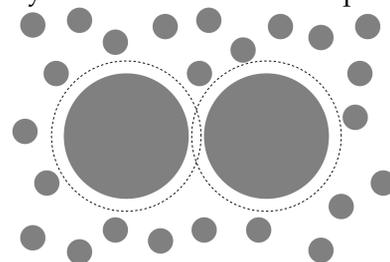


Figure 3: The depletion interaction. Small particles cannot enter the region enclosed by dashed lines.

The resulting potential depends both on the packing fraction and the radius of the small parti-

cles. We happen to have polymer particles, called poly(N-isopropylacrylamide), or NIPA, whose radius is dependant on the system's temperature (Fig. 4). These particles will be used to create colloidal samples which can melt and crystallize as their temperature is changed, allowing us to study the kinetics of the impurities in those samples.

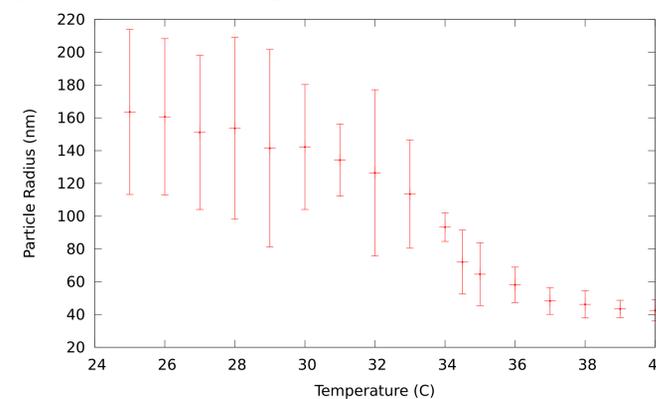


Figure 4: The radius of our NIPA particles as a function of temperature. The error bars denote polydispersity.

Elasticity and Strain

At the moment, our interest lies in the interactions which impurities have within static crystals. Since the equilibrium state of a thermodynamic system is at a local free energy minimum, and the formation of a crystalline lattice is one way which particles reach such a local minimum, the equilibrium state of an impurity-ridden crystal is that which minimises the displacement of particles from their lattice positions, or the *strain* on the crystal, due to those impurities. We suspect that strain will be minimised by grouping impurities together and in grain boundaries or other defects, and that their motion is aided by the movement of dislocations.

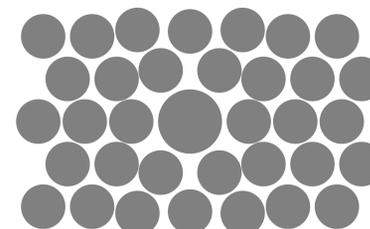


Figure 5: Irregularities in a crystal lattice due to the addition of an impurity.

Preliminary Results

We analyze our microscope images to find and tag *defects* in the crystal. A defect is a particle which has an abnormal number of neighboring particles. In our preliminary analysis, we have found that the proportion of large particles in defects is 0.47 ± 0.05 and that of small particles is 0.091 ± 0.001 . The propensity of large particles to gather in areas of low crystalline order supports our theories regarding their interactions with the static crystal.

Future Work

We hope to improve the construction and behavior of our ramp cells with more careful construction techniques and the addition of a nonstick agent to our samples. We would also like more opportunities for seeing the movement of large particles, which we hope to attain by both using depletion and building a set of optical tweezers, with which we will be able to move individual particles around. More computational analysis of our current data needs to be done to begin to quantify the relation of large particles and crystalline order.

More Information

- More information about our research can be found at <http://www.physics.hmc.edu/~gerbode/wiki/>.
- A copy of this poster is located at <http://mc.physics.hmc.edu/summer12-poster.pdf>.
- To contact our group with questions or other concerns, email gerbode@hmc.edu.

References

- [1] Craig B. Arnold and Michael J. Aziz. Unified kinetic model of dopant segregation during vapor-phase growth. *Phys. Rev. B*, 72:195419, Nov 2005.
- [2] B. Götzelmann, R. Evans, and S. Dietrich. Depletion forces in fluids. *Phys. Rev. E*, 57:6785–6800, Jun 1998.