The microscopic dance of magnetic particles

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Enviado por Joseph Alexander Monarres [2] el 7 agosto 2017 - 7:09pm

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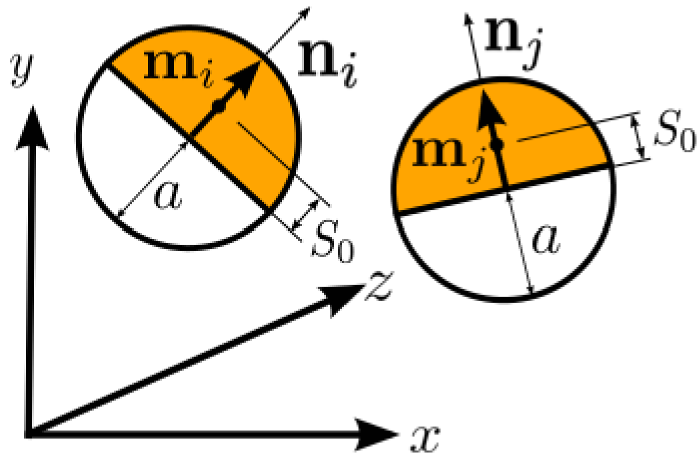
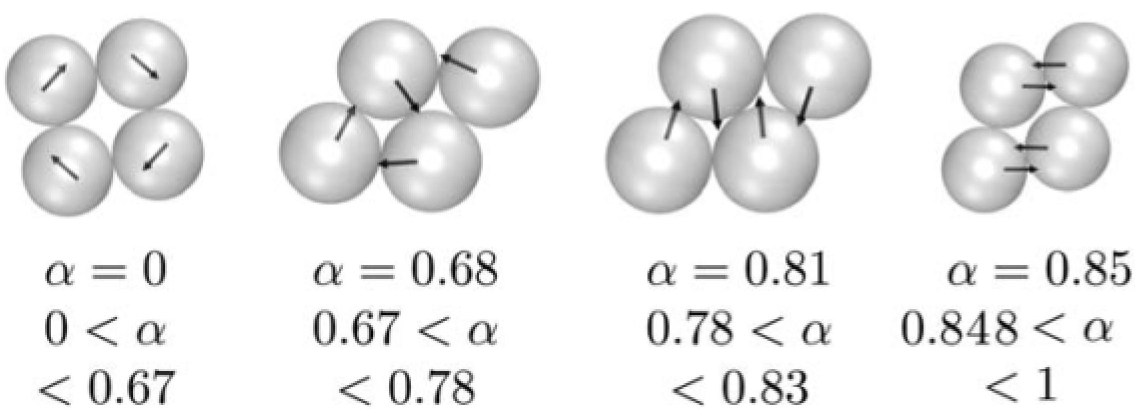
This summer has been a long summer full of new experiences and new opportunities to learn. I have been thrown fully out of my comfort zone and been forced to adapt to a broad range of new situations. I’ve had to learn many new things being in a place with a very different culture, that speaks a different language with a climate that is very different from my home in dry southern california. I had to learn to operate simulations using Bash, in a topic that I have no experience in: magnetic colloids. Most importantly of all, what I really learned was how to manage the pace and rigor of research and to be adaptable in areas outside my expertise.

The official title of my research was “Aggregation of Janus magnetic particles with axially shifted dipoles”. We were tasked with elucidating the dynamics of aggregation of special magnetic particles and how differing the shift fraction (S)- with .5 being halfway between the center of mass and 1 being on the particles circumference -and relative strength of the magnetic force (lambda) affect their behaviour. The word Janus comes from the two faced Roman of the same name; in a similar vein, Janus particles have two domains of differing physical characteristics. Our particles have a magnetic and non-magnetic domain, which causes the point dipole moment to be shifted from the center of mass towards the surface of the particle. In our case the particle points radially outward, hence the “axially shifted” designation. Using Brownian motion computer simulations, we can model these particles over time and document their movements in a quasi 2D environment.

One by one, the simulation calculates the net forces on each individual particle by adding up all the magnetic interactions vectors the target particle has with every particle in all of the boxes, with an added Brownian force vector in a random direction. The simulation then multiplies this net force value by the time step to find the exact displacement of the particle. Once It has done this for all of the particles, it adds all the displacements to their initial positions to move all particles at once. The simulation then moves to the next time step and repeats the entire process until the end time is reached.



The structure of the clusters was primarily determined by the value of S. Three distinct shift regimes were observed with unique structures: low shift head to tail single chains, medium shift omnidirectional island clusters, and high shift staggered double chains. The value of lambda did not change the observed cluster structures, however it did have an effect on the cluster structure by shifting what values of S shift regimes would appear. Raising lambda lowered the at which values that the medium and high shift regimes appeared.



Basic clusters with shift fraction α. From Klinkigt 2013

Cluster aggregation takes place in two distinct phases: nucleation, characterized by the formation of small clusters from single particles; and growth, characterized by the aggregation of clusters into larger clusters. Systems where lambda = 10 cannot form stable clusters and are dominated by a gaseous transitional phase of singlets at low shift and triplets at high shift. The value of lambda is the most significant factor in determining the rate of cluster aggregation as it determines how well particles are able to overcome the Brownian force to produce directed movement toward each other; larger lambda leads to faster aggregation. The value of S affects the rate of aggregation in a slightly more complex manner. Higher S leads to a stronger effective magnetic force because it allows dipole moments to get closer to one another, globally increasing the rate of nucleation. The rate of growth follows the opposite trend; as S rises, growth is slowed. The reason for this is that the higher shift clusters have a near zero net dipole moment; aggregation is further complicated for staggered chain clusters due to the fact that frowth only happens from each end of the cluster and only if the two aggregating clusters' end particles are oriented antiparallel to eachother..

The density of clusters is completely dependent on the specific cluster structure present. Systems with lambda=10 are unable to form dense clusters due to their instability. Clusters of the high and medium shift regimes are far denser than the that of the low shift regime. Dense clusters are able to effectively conduct heat and electricity. While island clusters are able to conduct electricity, their omnidirectional nature causes them to conduct in all directions. The linear nature of the staggered chains allow them to transmit signals in one direction. This in combination with the fact that the cluster structures of magnetic Janus particles can be changed using magnetic fields gives them potential applications as externally controllable conductors or wires.
