Simulating Superconducting Particles in a Cryomagnetic Trap

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Abstract

The goal of this work is to study a classical Coulomb system in a laboratory experiment [1]. The force used to counteract gravity and suspend the charged particles is based on the Meissner effect, in which the magnetic field is expelled from a superconducting material, so that superconductors may be considered as perfectly diamagnetic. A stable levitation of diamagnetic bodies is provided in a local minimum of the magnetic field balanced by gravity. The force on a diamagnetic particle is given by $F = (\chi m / 2)\, \nabla\, (B^2)$, where m is the magnetic moment, B is the magnetic field, and χ is a constant. The particles in the trap were then charged by a biased probe and formed interesting equilibrium structures [Fig 5]. A molecular dynamics simulation was used to attempt to replicate this structure. In addition to the force of the trap, the simulation took into account the the Coulomb interactions, Lorentz force, Gas drag, and magnetic interactions of the particles with each other. The equations of motion were integrated using the Runge-Kutta method to produce the velocities and positions of the particles within the magnetic trap as a function of time. Work on the simulation included adding collisions between particles, expanding the capabilities so it could run for longer periods of time and with larger numbers of particles, and tracking the energy in the system.

Background

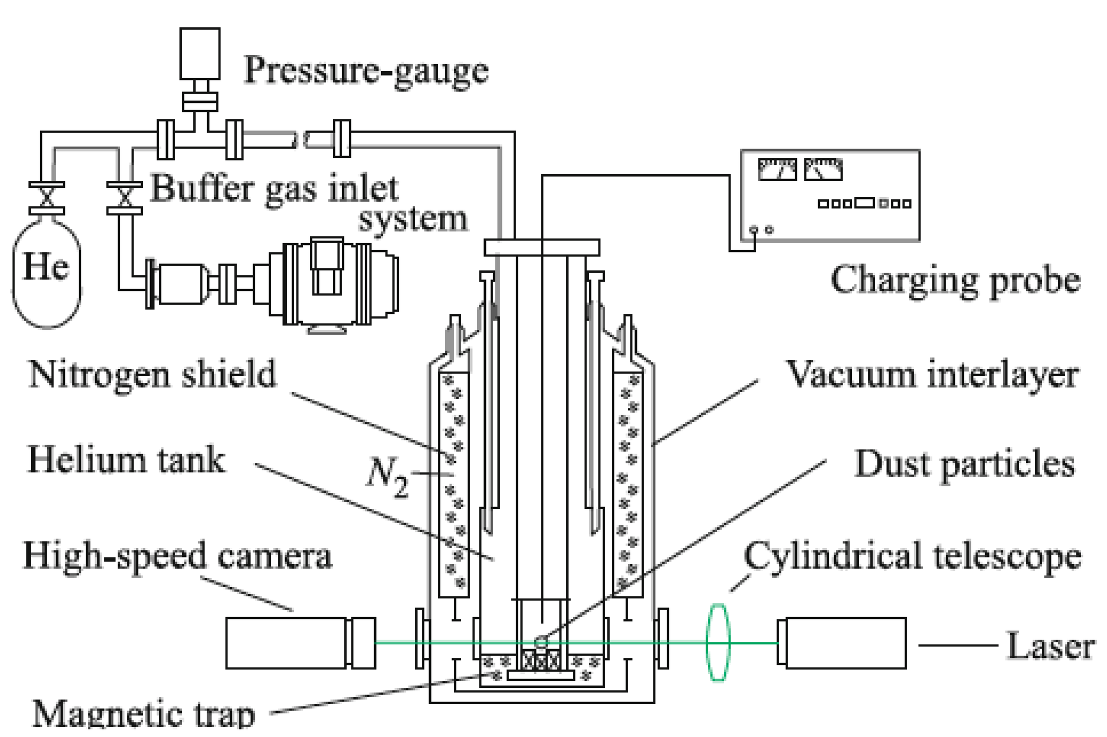


Figure 1 Is a representation of the experimental setup. [1]

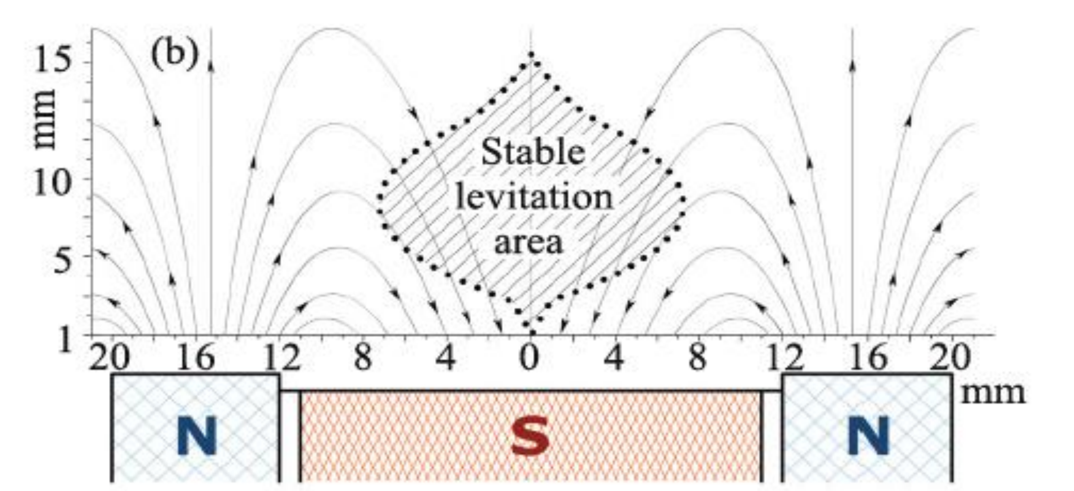
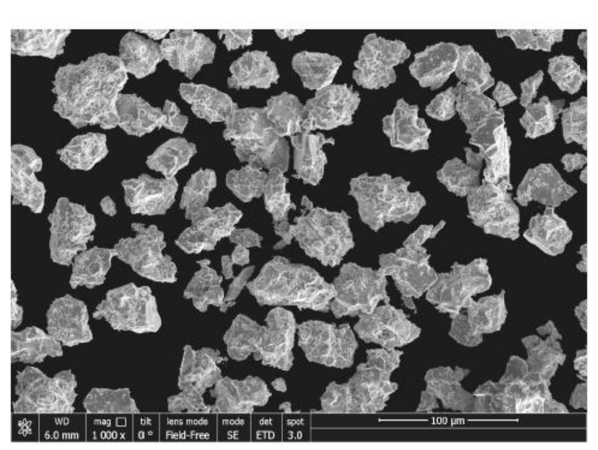
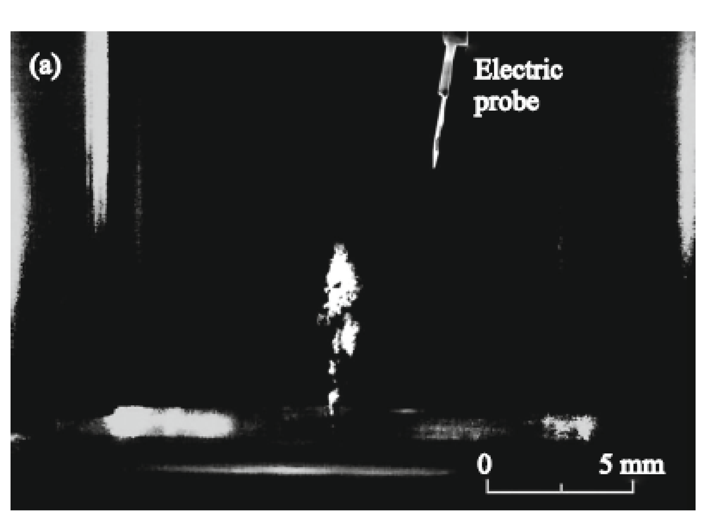


Figure 2 (above) Is the magnetic field trapping the particles [1]. They levitate because the particles exhibit diamagnetism, which is when an external magnetic field induces an internal magnetic moment. The induced field is opposite to the field exerted and cancels out the external magnetic field.



Size of particles: 30-60 µm
Material: $YBa_2Cu_3O_7$
Strength of trap: 2 magnets with fields of 0.5 Tesla
Probe Potential: 2000 Volts
Temperature: 77-91 K

Figure 3(above): The irregular particles used in the experiment are shown. Fig.4 (right): The clump of uncharged particles within the magnetic trap [1].



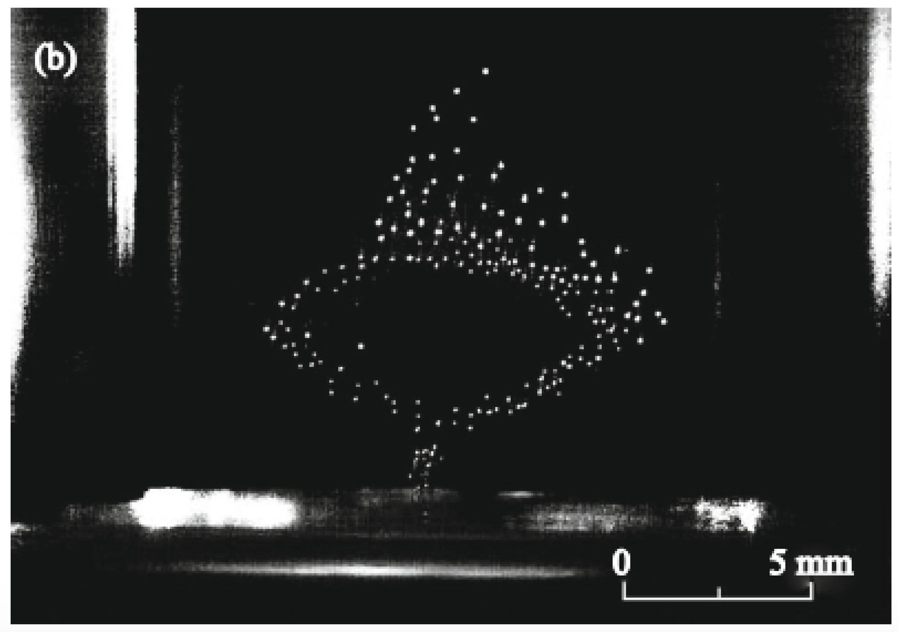
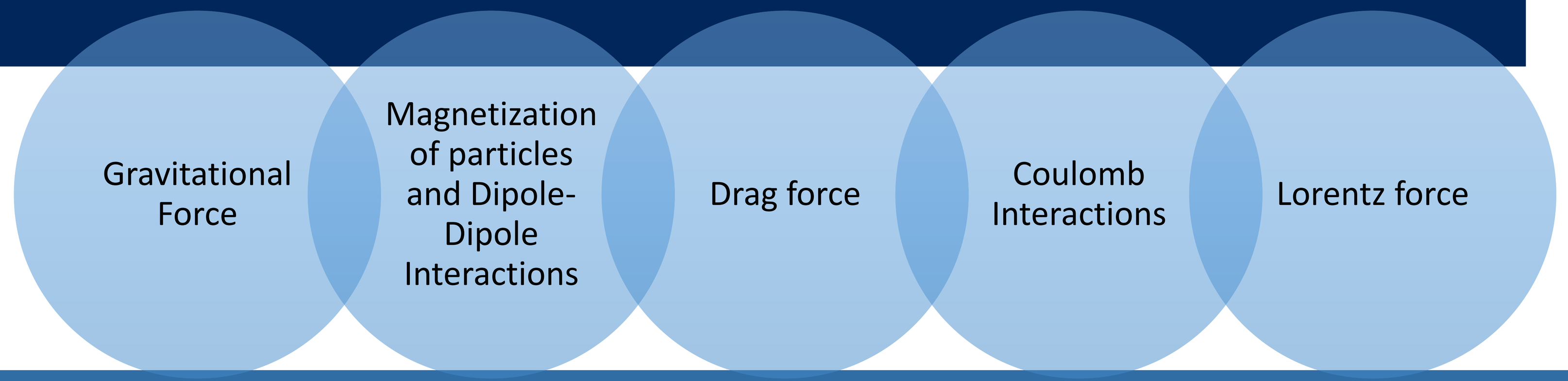


Figure 5 (above) Is the equilibrium structure formed by the charged particles [1].

Methods

A molecular dynamics simulation was used to take into account the forces involved in the experiment and calculate the particle's position and velocity [2].



Results

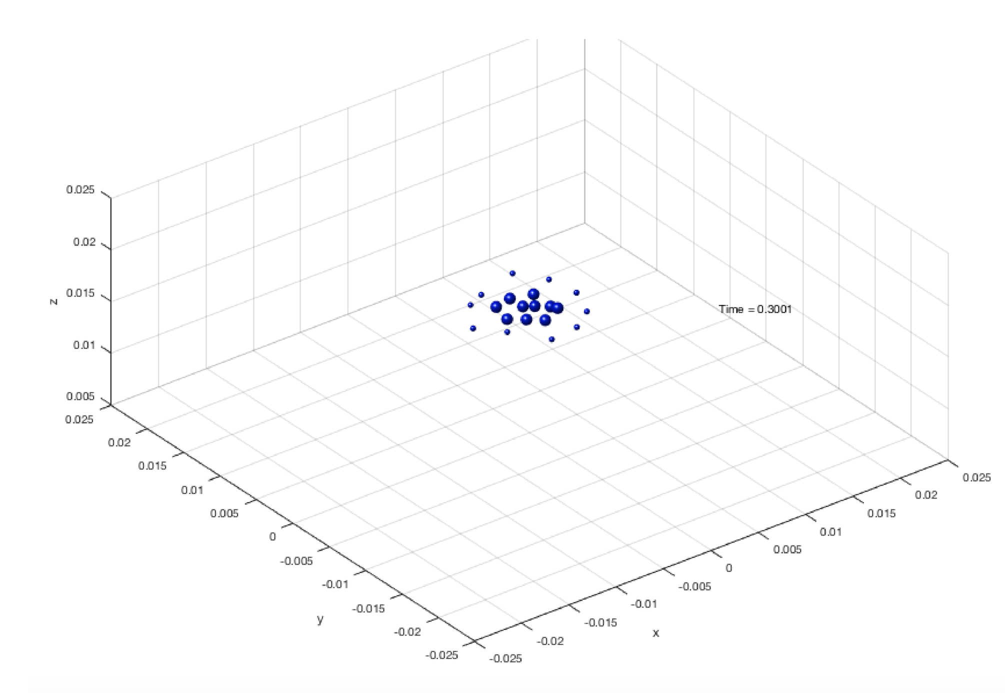


Figure 6: Simulation of 20 particles with radius of 25 and 50 micrometers. Each particle has a surface potential of 300 V. The collision coefficient of restitution was 0.75 and there was a gas drag of 20 inverse seconds. The equilibrium structure of the particles is a ring shape with the particles segregated by size.

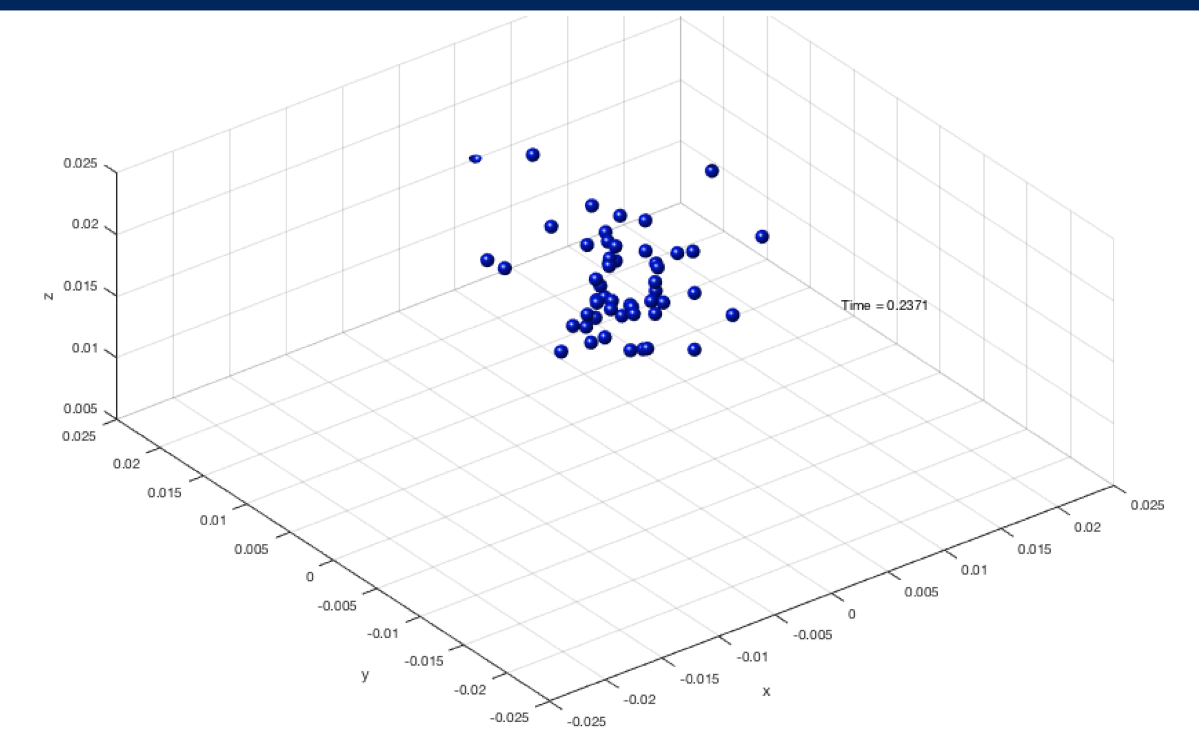
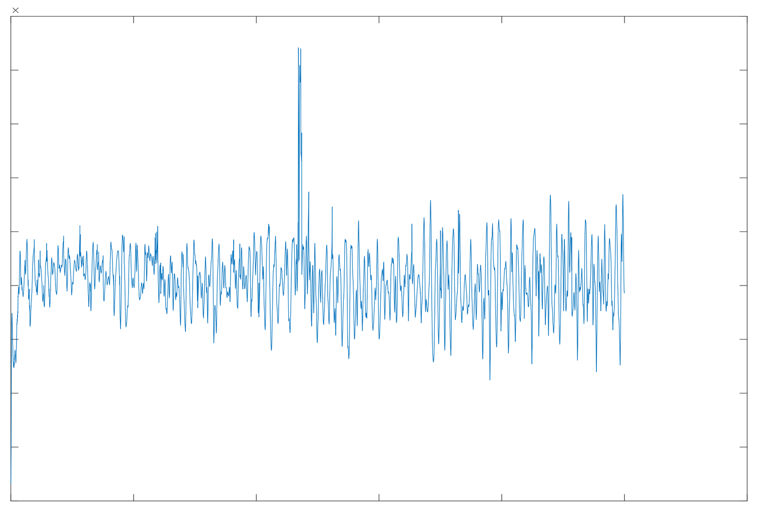


Figure 7: Simulation of 100 particles with radius 25 and 50 micrometers. Each particle has a surface potential of 150 V. The collision coefficient of restitution was 0.75. Gas drag was calculated using experimental parameters: 77 Kelvin and 50 mTorr . In this image you can see the clumping/sticking of the groups of particles.

Figure 8: Average total energy of particles. The energy remains fairly constant, but fluctuations are growing with time, hinting at a growing uncertainty related to a problem in the simulation or as a result of the disappearance of particles from the trap.



Time vs Energy

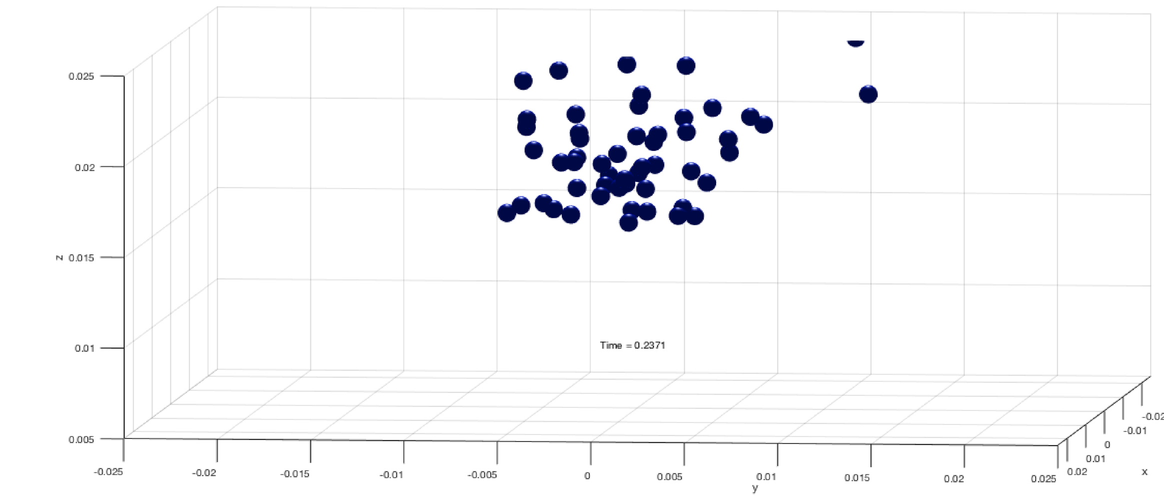


Fig. 9: Side view of the particles shown in Fig. 7.

Conclusion

- Equilibrium structure depends on the particle charge.
- Particles with charge formed clusters/chains due to the magnetic interactions.
- The discrepancy between the simulation and experiment could be partially due to differences in charge distribution.

Future Work

- Simulate larger numbers of particles, with a wider size distribution.
- Make the particles in the simulation a better approximation of the particles used in the experiment which were shaped more roughly than perfect spheres (see Figure 3).

Support

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References

[1] M.M. Vasiliev, O.F. Petrov, and K.B. Statsenko, JETP LEtters, 2015, Vol. 102, No. 11, pp. 771-774. Pleiades Publishing, Inc, 2015.

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