Announcements

- Gatoreval is available NOW!
- Homework 10 is due on Wednesday April 19.
- Homework 11 is due next Monday, April 24.
- Pop quiz is on April 26, Wednesday, at class time.

Last time

- Semiconductors

Today’s class

- Magnetic materials
- Undergrad research opportunities in the Guan lab
- Gatoreval (if time allows)

Magnetization and magnetic dipoles

When a magnetic field is applied, the magnetic moments rotate into partial or full alignment with the applied field, and the vector sum of the dipole moments gives the material a net magnetization.

Total magnetization M

$$\vec{\mathbf{M}} = \frac{\sum_{i=1}^{N} \vec{\boldsymbol{\mu}}_i}{V}$$

μ_i : individual atomic magnetic dipole moments
V: volume

magnetic susceptibility χ

The stronger the applied field, the more the individual magnetic moments rotate into alignment with the field.

In many materials, the net magnetization is directly proportional to the applied field B

$$\mu_0 \vec{\mathbf{M}} = \chi \vec{\mathbf{B}}$$

μ_0: magnetic constant, vacuum permeability, permeability of free space
$\mu_0 = 4\pi \times 10^{-7}$ T·m/A. T: Tesla, m: meter, A: ampere

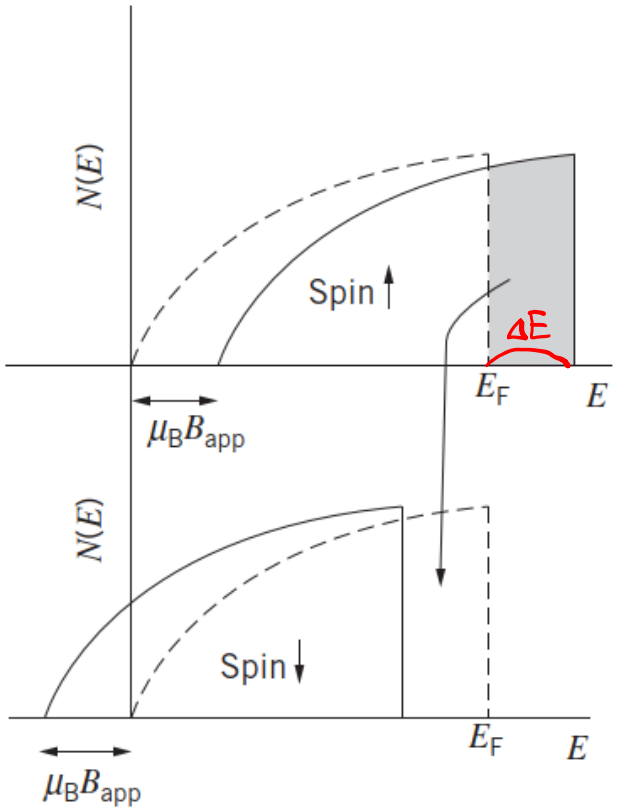
χ is typically small, ~10^{-5} to 10^{-1} , and positive -- “paramagnetic”
Negative – ‘diamagnetic’
Undefined in “ferromagnetic” material

Paramagnetism of Electron Gas

The energy of an electron in the field is

$$E = +/- \mu_B B$$

μ_B: Bohr magneton, 9.27×10^{-24} J/T
+/- is caused by spin.



The higher-energy electrons with spin up fill the vacant energy states in the spin-down group until the two groups equalize their Fermi energies.

Excess spin-down electrons.

Net magnetization.

Assumptions:
ΔE is small
Low temperature – sharp Fermi-Dirac distribution

Pauli paramagnetic susceptibility:

$$\chi = \frac{3\mu_0\mu_B^2}{2E_F}\frac{N}{V}$$

N/V: number of atoms per unit volume.

In-class exercise (5 min)

$$\chi = \frac{3\mu_0\mu_B^2}{2E_F}\frac{N}{V}$$

Calculate the susceptibility of Barium in SI unit per unit volume. The density of Ba is 3.50 x 10^3 kg/m^3 and the molecular weight of Ba atom is 137.3 x 10^{-3} kg/mole. The Fermi energy for Ba is 3.65 eV.

$\mu_0 = 4\pi \times 10^{-7}\ T\cdot m/A$, $\mu_B = 9.27\times10^{-24}\ J/T$

$\frac{N}{V} \Rightarrow$ assume materials with mass $m = \rho \cdot V$

mass of individual atom $\frac{M}{N_A}$

# of atoms $N = \frac{m}{\frac{M}{N_A}} = \frac{\rho\cdot V}{M}N_A \Rightarrow \frac{N}{V} = \frac{\rho N_A}{M}$ For Ba, # of e^- $\frac{2\rho N_A}{M}$

$$\chi = \frac{3\mu_0\mu_B^2}{2E_F}\cdot\frac{2\rho N_A}{M} = \frac{3(4\pi\cdot10^{-7}\ T\cdot m/A)(9.27\times10^{-24}\ J/T)^2}{2\cdot 3.65eV\cdot 1.6\times10^{-19}\ J/eV}\cdot\frac{2(3.50\times10^3\ kg/m^3)\ 6.02\times10^{23}\ \#\text{ of atoms/mole}}{137.3\times10^{-3}\ kg/mole}$$

$= \boxed{8.5\times10^{-6}}$

$1\ J/T = 1\ A\cdot m^2$

$$\frac{\frac{T\cdot m}{A}\cdot\frac{J^2}{T^2}\cdot\frac{kg}{m^3}\cdot\frac{1}{mole}}{J\cdot kg\cdot\frac{1}{mole}} = \frac{J}{AT}\cdot\frac{1}{m^2} \rightarrow \text{dimensionless}$$

A follow-up question

Centimeter-gram-second

↑ cgs

χ_{molar} measured

We found in literature, the experimental measured susceptibility is 20.6×10^{-6}.

If the theoretical model is correct, what factors could have caused the discrepancy?

Calculated χ^{SI}_{volume}

$$\chi^{cgs}_{volume} = \frac{\rho}{M}\chi^{cgs}_{molar}$$

ρ, M in cgs units

$$\chi^{SI}_{volume} = 4\pi\chi^{cgs}_{volume} = 4\pi\frac{\rho}{M}\chi^{cgs}_{molar}$$

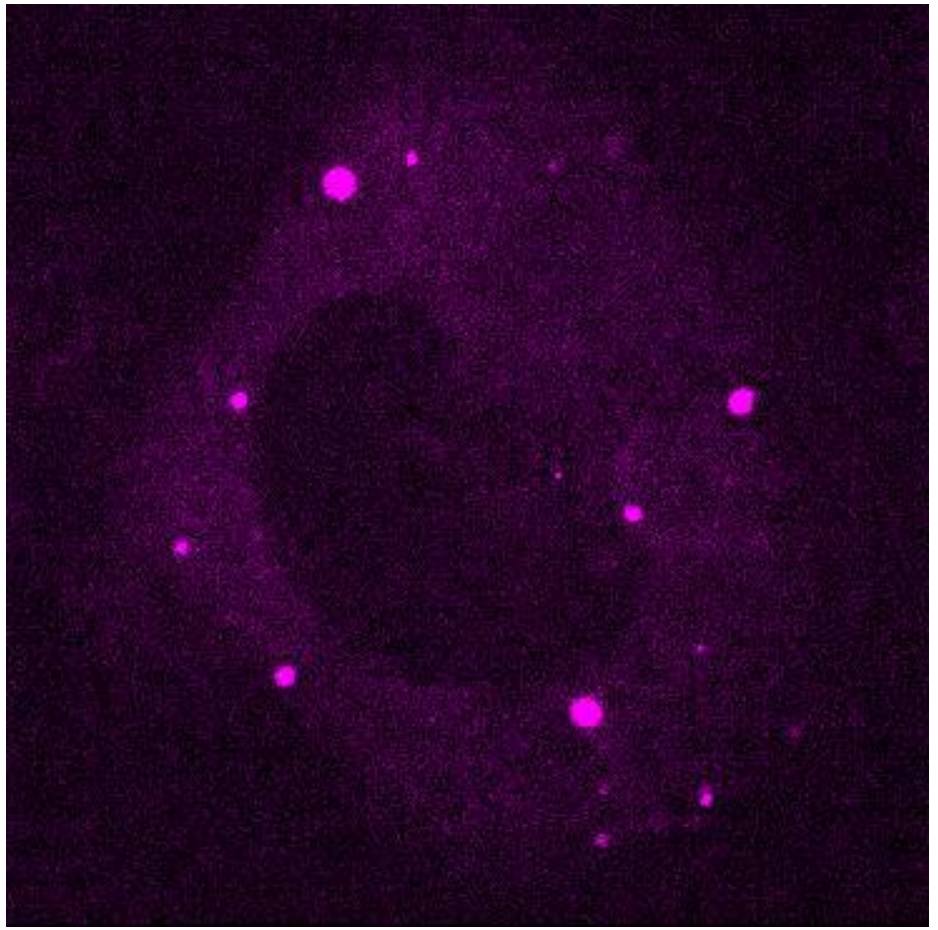
$$= 4\pi\left(\frac{3.50\,g/cm^3}{137.3\,g/mole}\right)\cdot 20.6\times10^{-6} = 6.6\times10^{-6}$$

We provide strong support to undergrads

Excellent track record:

- Sasank Desaraju (Physics), Fulbright semi-finalist.
- Jewel Ashbrook (Physics), Biophysical Society Travel Award.
- Abdul Dozic (Physics), Cornell University Bioengineering Program.
- Reagan McGinley (Microbiology), University Scholar Program.
- Vivian Nguyen (Biology), Bristol Myers Squibb Science Scholar Program.
- Kyle Scheller (Microbiology), University of Florida Biomedical Science Program.

What do we do?



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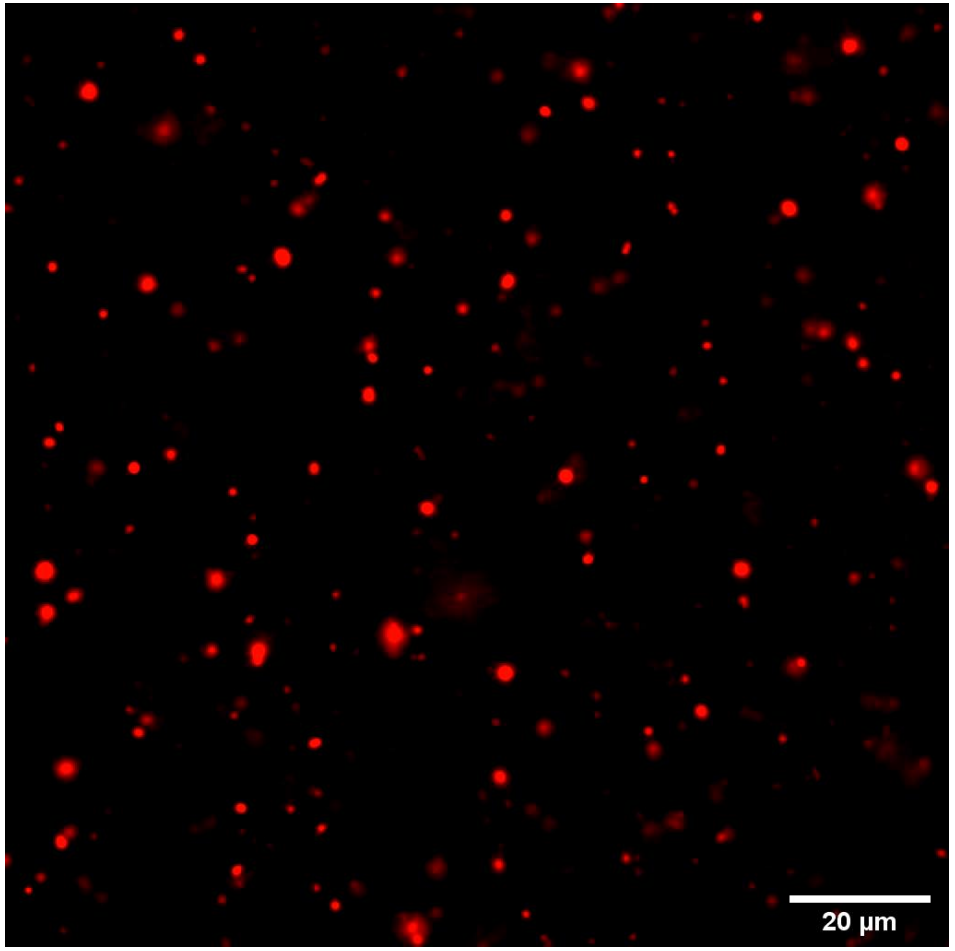

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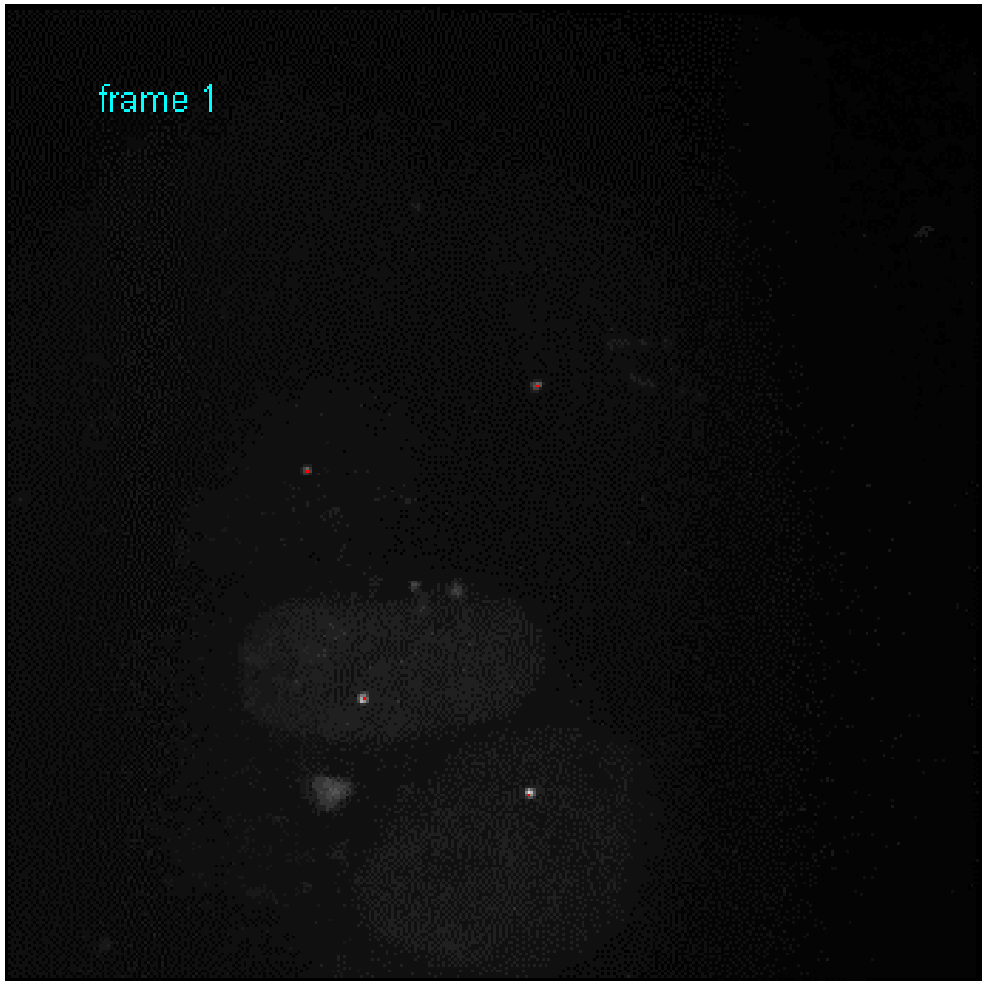

Openings for undergraduate researcher after the summer

Contact Prof. Guan by August 10. Do not email before August.

NO prior biology knowledge required!

One opening, computational –

simulation project for RNA vaccine microstructure assembly

big data analysis project at whole proteome level for cancer mutation

One opening, experimental –

advanced fluorescence imaging

You might be a good fit if …

Motivation – seriously thinking about grad school or med school.

You can commit at least 15 hours per week, in blocks of time of 3-5 hours during 9-5 weekday

Previous research and programming experience is a plus, but not required.

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