# Magnetic Fano Interferences in Plasmonic Metal Oligomers


## Claire West

**Physics, University of California, Santa Barbara**

***NNIN REU Site: Washington Nanofabrication Facility and Molecular Analysis Facility, University of Washington, Seattle, WA***

*NNIN REU Principal Investigator: Professor David Masiello, Chemistry, University of Washington*

*NNIN REU Mentors: Dr. Charles Cherqui and Steven Quillin, Chemistry, University of Washington*

*Contact: clairewest@umail.ucsb.edu, masiello@chem.washington.edu, cherqui@uw.edu quills@uw.edu*



## Abstract:

**Plasmonic metal nanoparticles possess exotic optical properties impacting a variety of fields from basic science to energy, defense, and medicine. One such property of broad importance is a Fano interference. This interference can be modeled by two coupled charged oscillators, in which the driven bright mode transfers its energy to the dark mode and stops. Thus, the system is still absorbing energy, but does not scatter. The resulting localization of energy is dependent on the coupling strength and mass ratio of the oscillators. These parameters, when properly tuned, alter the Lorentzian nature of the scattering spectrum, leading to an asymmetric Fano lineshape. The conditions that produce a Fano lineshape in the oscillator model were used to predict parameters in electric and magnetic plasmonic nanoparticle systems. This research focused on showing magnetic-magnetic Fano interferences for the first time. In particular, a magnetic plasmon was created from a cyclic assembly of metal nanospheres each with an electric dipole oriented head-to-tail around the ring, mimicking an electrical current loop. A second plasmonic ring was coupled to the first and driven by an electron beam, and their resulting interference was studied through numerical simulations of Maxwell's equations.**


## Introduction:

Plasmonic nanoparticle assemblies offer a variety of tunable properties that are highly dependent on the separation of the particles. If the particles are close enough such that the plasmons interfere with each other through near-field interactions, they may experience a Fano interference. This interference is observed by analyzing the light scattered and absorbed from the system, and pinpointing the energy that corresponds to a dip in the scattering spectrum where there is non-zero absorption. This effect has been observed between electric-electric plasmon interferences [1], and electric-magnetic plasmon interferences [2]. But for the first time, this project focused on understanding the Fano interferences between magnetic-magnetic plasmons on a different configurations of nanospheres.

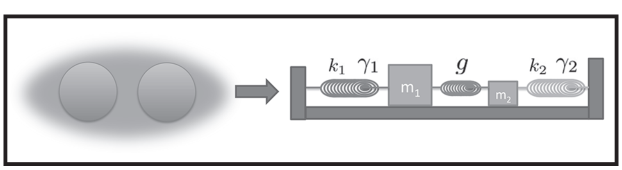


*Figure 1: Oscillator system to model plasmonic interferences where $k_1$, $k_2$, and g represent spring constants, and $\gamma_1$ and $\gamma_2$ represent damping coefficients.*

## Methods:

The interferences between plasmons were modeled using a damped oscillator system, because the time-dependent dipole moment of a nanosphere in an oscillating electric field is proportional to the Green's function of the damped harmonic oscillator. Figure 1 shows a schematic of this model. The Hamiltonian of this system can be diagonalized to solve for the new hybridized eigenmodes, which represent the electric dipole orientations. The parameters of this model were tuned until the Fano lineshape was most clearly seen in the spectra, which occurred when the masses of the oscillators were different and when the coupling was small. For the first time, this understanding of which parameters produced Fano interferences was used in an attempt to induce a Fano interference between two magnetic modes.

A nanosphere configuration motivated by previous research [3] was adapted to excite a magnetic plasmon Fano interference. Cherqui, et al., excited a ferromagnetic and antiferromagnetic mode on a hexamer oligomer configuration as shown in Figure 2a. An electron-beam was placed next to one sphere to excite the electric dipole on that sphere to point in a given direction and polarize the other dipoles.

The two eigenmodes under consideration were the modes that corresponded to the dipoles orienting head-to-tail because they produced a ferromagnetic and an

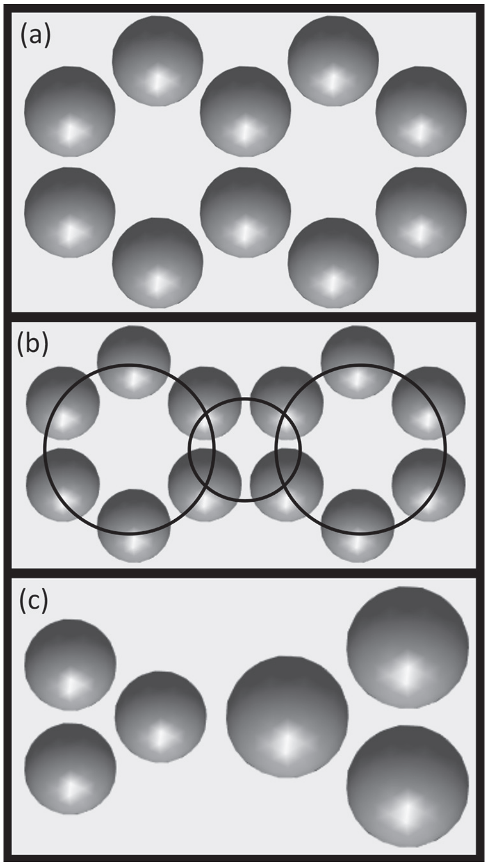


*Figure 2: (a) Fused ring system motivated by Cherqui, et al. (b) Separated hexamer system with three magnetic moments circled. (c) New triangular configuration to eliminate third magnetic moment.*

antiferromagnetic mode. As learned from optimizing the parameters in the oscillator model, the coupling between the modes had to be small, and therefore the hexamer oligomer configuration was modified by separating the hexamers.

## Results and Conclusions:

Ferromagnetic and antiferromagnetic modes created from plasmonic nanoparticle systems were attempted to be excited through numerical simulations on two different nanosphere arrangements. The separation of the rings and the placement of the electron beam were independently varied to excite the two different modes.

In the two hexamer system, the ferromagnetic mode could not be excited due to interferences generated from a magnetic moment that formed from a third electric dipole loop, shown in Figure 2b. Therefore, a new configuration was considered with two separated triangular nanosphere assemblies as shown in Figure 2c. Through various placements of the electron beam and separation distances of the triangular rings, it was realized that although this configuration corrected the previous problem, the

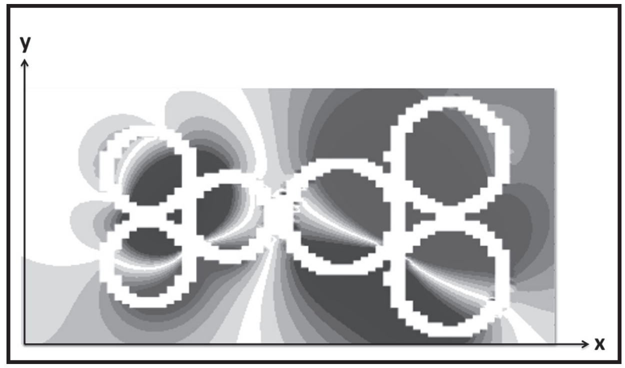


*Figure 3: Magnetic fields in triangular system did not form localized moments.*

magnetic modes did not completely close in and become localized, as shown in Figure 3.

In conclusion, by changing the ring separation and electron beam placement in two different configurations, a ferromagnetic mode was never excited.

## Future Work:

For the future work on this project, a new configuration must be considered in order to excite these two localized magnetic modes. One possible system would be to amend the triangular arrangement and add a fourth nanosphere to each triangle in order to form the magnetic modes.

Once this system achieves the desired ferromagnetic and antiferromagnetic modes, the scattering spectra can be analyzed to find the Fano interference. The ring distance and nanosphere separation can be varied and optimized to analyze which conditions produce the Fano effect.

## Acknowledgments:

This work was supported by the National Science Foundation's NNIN Research Experience for Undergraduates Program via grant number ECCS-0335765. I would like to thank Professor David Masiello for supervising me, and Charles Cherqui, Steven Quillin, Nick Montoni, and Niket Thakket for advising me during this project. I would also like to thank Melanie-Claire Mallison for organizing this program.

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