Fluorescent Quantum-Sized Carbon Dots Isolated in an rf Paul Trap

Sigma Pi Sigma Undergraduate Research Award Proposal
The Citadel, the Military College of South Carolina
Charleston, South Carolina

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Abstract

Recently discovered nanoscale carbon particles, known as carbon dots, have attracted much attention from the scientific community in their ability to fluoresce brightly and for potential use in nanoscale devices. Previous studies have revealed a direct relationship between size and luminescence in carbon dots, however, this relationship remains unexplored outside of solution. Although a variety of theories have been derived to identify a mechanism supporting this relationship, it is not fully understood or known to exist outside of solution. Using an rf Paul trap design with electrospray ionization, the ExCitAtIon group at the Citadel aims to isolate and study these carbon dots in the absence of solution. The as described relationship will be tested for in these “naked” carbon dots to better understand the mechanisms involved in this unique property.
"Experiments at the Citadel on Atoms and Ions" or ExCitAtIon, is the newest research group of the Citadel’s department of physics. Headed by Dr. Robert Clark, the group is focused on ion trap fabrication, design and application. The ExCitAtIon group proposes to develop a radio-frequency (rf) Paul trap to isolate carbon dots for use in experimental studies of their properties. Specifically, carbon dots (C-dots) in solution exhibit a unique property, typically displaying size and excitation wavelength ($\lambda_{ex}$) dependent photoluminescence behavior.\(^1\) In general, smaller C-dots yield higher photoluminescence than larger C-dots with similar surface passivation. Mechanistically, it has been stated that there must be a quantum confinement of emissive energy traps to the particle surface for carbon dots to exhibit strong luminescence upon surface passivation.\(^2\) This property and the described mechanism remain unexplored in C-dots separated from any organic molecules that would allow for surface passivation. The electrospray ionization technique will be used for both removing solution and trap loading, while the ion trap is to be used for experimentation. Our project aims to test for this relationship in “naked” C-dots and to further assess the described mechanism by experimentation. Through this project we hope to further develop the understanding of C-dots, which are attracting considerable attention as nascent quantum dots, particularly for applications for which the size, cost, and biocompatibility of the label are critical.\(^1\) C-dot samples are provided through collaboration with Professor Ya-Ping Sun of Clemson University’s department of chemistry. The project will be organized into cumulative phases which include: trap design, trap fabrication, dot separation, testing for photoluminescence, experimentation, analysis and assessment.

The initial trap design will be that of an rf Paul trap. In this design an applied rf potential is used for radial confinement while dc potentials are applied for axial confinement allowing for C-dot isolation. Dots will be loaded into the trap via an electrospray ionization apparatus. It will be noted that the large voltages required for electrospray mean that it is most easily performed at or near atmospheric pressure.\(^3\) Charged C-dots will pass from the ionization source into an acrylic vacuum chamber.
containing the trap electrodes. The electrodes will most likely be that of a simple ring design, in which the geometry still gives a useful trap potential and the relatively small size allows for good observation. Less emphasis will be given to electrode design, however, as mainly proper electrode function is more important for our experiments. Electrodes will be connected to an external function generator. The design of the acrylic chamber will allow for a camera mount, light source and appropriate BNC connections. A camera will be mounted to the chamber and used to observe “naked” C-dots and study their interactions with the light source. The department’s own Opolette Nd:YAG tunable laser system will serve as the light source, allowing photoluminescence to be tested at a wide range of wavelengths. A SPEX 1000M spectrometer, also provided by the department, will be positioned for optimal performance required by experimentation.

Isolating C-dots outside of solution is a key requirement for this projects success. This can be accomplished through the electrospray ionization technique, which was previously proven successful in the isolation of graphene flakes. The electrospray process will involve applying a high voltage to the liquid solution of C-dots at a sharp tip. Strong electric fields at this tip blow off fine droplets of solution, and as solvent evaporates from these charged droplets, self-repulsion breaks them up into smaller particles, eventually producing individual charged solute particles. The C-dot solution will be diluted with a highly volatile chemical, most likely methanol, which will aid evaporation during the separation process.

C-dot photoluminescence will be tested using two different methods. One method requires that the laser be timed while watching the total emission from the C-dots on a photodiode. The second method considered is to use the SPEX 1000M grating spectrometer to measure emission as a function of wavelength. We will be testing dots synthesized in different organic solutions, as to better understand
the significance of the organic molecules. This entire process is scheduled to be completed during the 2012 fall semester.

The question remains of what expectations are there in performing these C-dot experiments. The fact is that no one knows how C-dots will respond outside of solution but we can, however, determine the appropriate procedures to follow depending on their reaction. If the C-dots do fluoresce outside of solution we can conclude that energy trapping does not depend on the solution and in fact it may be an intrinsic property of the C-dot. We will be able to verify this by using dots synthesized with different organic molecules. This is something that the group is extremely excited about and a crucial to understanding these particles. Another experimental direction is the study of the environmental effects in C-dots by testing their energy relaxation.

The funding would benefit the Citadel chapter in a variety of ways. Primarily, the funding will be used to aid the ExCitAtion group in development within the department. The money will be used for necessary parts required for a fully functioning trap. Gaining these parts will also help expedite the fabrication process in hopes of experimenting earlier. The construction of this project will likely cause more interest in the ExCitAtion group, which would likely cause an increase in this chapter’s membership rate. In addition, tools attained for this research can be used in other research projects as well, benefiting more than one group. The department as a whole will benefit through this funding as well.

5. Pearson, C.E; Leibrandt, D.R; Bakr, W.S; Mallard, W.J; Brown, K.R; Chuang, I.L Physical Review A, 2006, 73 032307
### Proposed Budget

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<th>Item</th>
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**Total Budget and Funds Requested:** $1900.00