Modelling Interactions between Magnetic Nanoparticles in a DNA Hinge

UNDERGRADUATE RESEARCH

By

Avidaan Srivastava

Physics / Astronomy and Astrophysics
DEARTMENT OF PHYSICS
Arts and Sciences
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Mentor
Dr. Esther E. Gottlieb

PROJECT ABSTRACT

I have chosen to partake in undergraduate research for my STEP project. I have been working on this project under Dr. Ezekiel Johnston-Halperin, from the OSU Physics department, since the AU19 semester. The Project as a whole, deals with the behavior of magnetic nanoparticles placed on different locations on each arm of a DNA hinge. So far, I have been analyzing and modifying an existing piece of code, written by a graduate student member of the research group, that aimed to theoretically model the interactions between these nanoparticles and throughout the summer my objective is to build on this code and make the model as foolproof as I can. After the model is complete, the next step is to finally conduct the experiments and determine any inconsistencies between the results obtained from the model and actual experiment.

I plan to spend the entire summer, from May to July, working on this project. Since I will be doing research full time, I would be contributing approximately 30 hours per week towards working on the code. It will be a transformational experience for me as I have never worked on any research projects before, so this gives me the perfect opportunity to gain experience ,in not only working in research groups, but also the theoretical aspects of doing research. It will be pivotal in helping me decide if I want to pursue Theoretical Physics or Experimental Physics as I plan to go to graduate school and get a PhD. in Physics. Additionally, being involved in undergraduate research will be crucial in giving me an edge when applying to graduate school.

PERSONAL STATEMENT

I am a sophomore at The Ohio State University double majoring in Physics and Astrophysics. My interest in Physics developed in 7th grade when the 'science' subject in our school was separated into Physics, Chemistry and Biology. In my very first physics lecture, the professor just walked into the class and without saying a word wrote '3' and '3m' on the black board in two separate columns and asked us the difference between the two. I was blown away by the fact that just the addition of a 'meters' after the '3' could change an insignificant, arbitrary number into a physical quantity that can be observed in real life. In 8th grade my school organized a trip to the Kennedy Space Centre in Florida and going on that trip helped a great deal in increasing my interest in Space Sciences.

Star Wars was a big part of my life growing up. Not only because of the Science Fiction elements but also because Luke Skywalker was one of my greatest inspirations. I learnt the value of never giving up and keep pushing harder to achieve my dreams. I also learnt that no matter how difficult or negative a situation may seem, there is always a positive aspect associated with it. It may take me a while to find that positive aspect, but it's always there. Another one of my personal values is hard work and helping others, something that I try to do every day in the Physics Lounge, in Smith Lab while working on Physics 2300/2301 homework. Hence why I worked as a TA twice for the Astronomy Department, under Dr. Laura Lopez and Dr. Barbara Ryden, which provided me with the valuable experience of learning how to grade home-work and exams, and also efficiently teaching other non-STEM majors basic scientific principles in a way that makes sense to them as science may not be everyone's strong suit.

My parents had the philosophy that other than being good in studies, I needed to learn at least one musical instrument and be good at one sport. Therefore, other than my academics I love playing Guitar and Keyboards (my favorite band being AC/DC), as a means of relaxation when I'm stressed, and play Lawn Tennis, to keep myself physically fit. However, I have always been really fond of watching Formula One races on T.V. A fun fact about this is that a week before I was born in 2000, Michael Schumacher won his first World Driver's Title for Ferrari. As a kid, I read Nobel Prize laureate Richard Feynman's autobiography and the way he talked about physics and how becoming a scientist was so interesting made me want to pursue a career in STEM disciplines. Also, the fact that he got to work on the Manhattan Project, which opened a whole branch of physics dealing with high efficiency energy sources makes me want to be just like him, make a difference in the world. One of his quotes that really inspires me is '*The first principle is that you must not fool yourself – and you are the easiest person to fool'*. I realized that in order to do my very best, I need to completely think things through, whether it's a physics problem or a life problem. I must figure not only how to correct my mistakes but also question myself on why my thinking process lead me to make that decision. Being involved in science made me learn a lesson in critical thinking i.e., making sure my argument doesn't have flaws before presenting it to others.

Personally, I believe education, knowledge, and family are my greatest priorities in life because I was raised in a household that enforced the importance of getting a stable job and earning, making academics the way to go. Looking forward, I want to get a PhD in Astrophysics and make a significant contribution in the space sciences, be it working for Indian Space Research Organization (ISRO) or doing research at a university. To achieve this, I need as much research experience as I can get at an undergraduate level, which is also my STEP final project. In the AU19 semester, I got involved in a research project in the Physics department doing numerical modelling for a condensed matter lab and throughout the summer I plan to use the STEP funding to continue on with this project. I think working on this project has certainly helped me think more creatively about problems and also made me realize that the answers are not at the back of the book all the time. Sometimes "you have to do your best and trust that your work is right."

PROJECT DESCRIPTION

Organic nanoscale structures such as DNA hinges are on the forefront of DNA origami. One of the ways to control these nanoscale machines is coupling them with an external control, such as a magnetic field. In this project, we attempt to control the hinge angles by placing magnetic nanoparticle on different sites along each arm of the DNA hinge. Specifically, Super-Paramagnetic Iron Oxide Nanoparticles (SPION) are the magnetic substance used for this experiment. SPIONs are essentially nanoscale magnetite (Fe_3O_4), that exhibit paramagnetic behavior when placed in an external magnetic field. The SPIONs placed on either arm of the hinge, for a specific hinge angle, settle with their magnetic moments pointed in a particular direction to give the lowest energy configuration. A similar experiment was previously conducted using Gold (Au) nanoparticles instead of SPIONs.

Some work has already been done on this by a member of my professor's research group. It was concluded that, at the nanoparticle scale, the most accurate description of the change in the SPION's magnetization is given by the Landau-Lifshitz-Gilbert (LLG) equation as the magnetic moment of one SPION affects the orientation the other one and vice versa. Another component to determining the orientation of the magnetic moment is thermal fluctuations, whose contribution can no longer be ignored due to the small-scale nature of the particles. It was assumed that the thermal effect can be averaged out to be a scalar effect as the time scale of thermal interactions is fast when compared to magnetic interaction.

So far, a simplified case, of fixing the magnetic moment of one SPION, relative to the hinge arm, and letting the moment of the other SPION be freely affected by it in addition to accounting for thermal fluctuations for a wide range of hinge angles was considered and the average magnetic free energy for each of the configurations of the SPIONs was calculated thus giving the most stable cases.

Going forward, the goal of my project is to theoretically model the scenario where the first SPION is also freely influenced by the moment of the second one. Since this process is fairly complicated, we have decided to first consider the case where the thermal variations are negligible, i.e., the external temperature is zero. The next step is to include thermal variations for both the SPIONs thereby taking the external temperature as an additional parameter. Previously, the code for modelling was written in Mathematica, however due to the complexity of the problem, we have decided to initially try to model it in Python, making it easier to debug and try different programming techniques, and then translate it back into Mathematica.

PROJECT GOALS

My primary objective of getting involved in the research project is to learn as much as I can about what is involved in doing research when pursuing a career in Physics. Undergraduate research is also a great way to prepare me for graduate school as I plan to eventually get a PhD. in Physics. This includes learning about the ethics of working in research groups, programming techniques, presenting ideas in an efficient way, writing scientific articles, etc. In addition to that, working in a highly respectable research group with people who are experts in their fields of study will help me develop my research skills and open research opportunities in the future.

This project, in its current state is completely theoretical, so working on it may help me decide if I prefer Theoretical Physics to Experimental Physics or vice versa. The programming language that the previous code was written in was Mathematica and decoding it really helped me understand the language better and also helped me learn some programming tricks that I can apply in the future, with other languages as well.

I'm also majoring in Astrophysics and a lot of research in that field is related to writing elaborate computer code to analyze interstellar objects, therefore my work in numerical modelling for a condensed matter experiment will provide me with a lot of experience needed for research in Astrophysics, thus enhancing my skill set. However, on the most fundamental level, my goal in life is to learn as much as I can about how everything in the universe works, from a nanoscale to a galactic scale and utilize my knowledge to contribute to the scientific community.

PROJECT BUDGET

Since, I will be doing research full-time, I am not allowed to take any classes at OSU and as a result of that, I am not permitted to live on-campus for the summer semester. I do not have any relatives of family friends to stay with during the summer so I will be leasing or subleasing a place to stay off-campus which is why the majority of my STEP funding would contribute to paying for the rent and utilities. I have found a location within walking distance of the Physics Research Building to minimize travel costs and also to maximize my safety in going to and from the university, especially with the recent threat of COVID-19 virus. The university dining plans will also not be active so I will be using the remainder of my available funding to pay for food and groceries throughout the 3 months of summer. Lastly, I may encounter some unforeseen expenses, such as formal wear for conference presentation, however I have not included them in my budget plans as there is an uncertainty associated with these expenses.

EXPENSE	MONTHLY COST	TOTAL COST
RENT	$450	$1,250
UTILITIES	$100	$300
FOOD/GROCERIES	$300	$900
TOTAL		$2,450