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Although I, like many of my classmates, appreciated physics in high school, I did not really learn what the field included until end of my freshman year and my sophomore year. These semesters included courses in electromagnetism, special relativity, and quantum mechanics. I still remember the incredible lesson that magnetism is a relativistic effect of electric interactions. Connections between seemingly different areas of study continued to appear as I worked farther through my courses. Along with various math and computer science courses, I have optimized my physics curriculum to reach interesting advanced physics courses, such as general relativity my junior year and quantum field theory my senior year. The connections between different topics or different courses have persisted. Even this semester, I had the pleasure of covering symmetry breaking and renormalization in a statistical physics class and a quantum field theory class in the same two weeks.

I started my first independent work, a junior paper entitled "Distinguishing B-Mode Sources in the Cosmic Microwave Background," not knowing exactly what I wanted to study. I didn't know what I wanted to work on, just that I wanted a project that was at least partially theoretical. I ended up working with Professor Suzanne Staggs, a cosmology experimentalist, on a theoretical project to estimate the power of upcoming cosmic microwave background measurements to constrain early-universe magnetic fields. One fun connection was the use of spherical harmonics to decompose perturbations in the CMB, a mathematical construct I has so far only seen in the hydrogen wavefunctions. I used a cosmology simulation code to see the effects of early magnetic fields on B-mode polarization. The code was written in Fortran, and I only interacted with it using a Python interface. Although I enjoyed using tools from computer science to understand physics, I felt lost in not knowing what the code was doing. Between the demands of more advanced junior year courses and competing on the varsity cross country team I did not put as much time into this research as I would have liked. Part of the problem was that in the beginning of the project I was afraid to admit when I did not understand important concepts. I resolved to learn from this project to improve in my next junior paper. I also learned that my interests lay in the more theoretical fields.

My second semester of independent work, "Ground States and Entropy of the Supersymmetric SYK Model," gave me the opportunity to choose a new area of research to pursue. I chose to work with Professor Herman Verlinde, a high energy theorist who specializes in string theory. Although I would not be able to work directly on his work, he was able to find me a topic suited to my level of preparation. He suggested I work on a supersymmetric generalization of the Sachdev-Ye-Kitaev model, consisting of N randomly interacting Majorana Fermions, with applications to both high energy and condensed matter physics. The benefits of the SYK model included helping me learn about advanced concepts such as quasiparticles and supersymmetry. The supersymmetry was particularly fascinating because it made me focus on an aspect of quantum physics I had not understood earlier, the interpretation of particles as modes of a harmonic oscillator. I initially struggled with understanding this new material, especially since I was learning it from papers rather than a textbook. Drawing on my experience in my previous independent work, I made a point of clearing up my confusions with my advisor, giving me a stronger understanding of the concepts. Part of this improvement was learning to not go too deep into a new topic at the expense of learning other important topics. I wrote Python code to numerically count ground states in the model. The large number of ground states in the model can result in nonzero entanglement entropy at zero temperature, one of the reasons for interest in the model. Although the simulation was simple, writing the code myself forced me to have a stronger understanding the physics behind it. I was able to show that the number of ground states is consistently above the analytic lower bound, and often far above the bound.

For my senior thesis, I am working with Professor David Huse, a condensed matter theorist, in order to get an introduction to more of the types of theoretical physics available in the department. My thesis research focuses on entanglement growth in random unitary circuits, a topic that attempts to explain how information loss in hydrodynamics can arise from unitary quantum mechanics. I am again writing my own code, now to simulate quantum circuits with random architecture. When the dimensionality of the spins at each site becomes high, any unitary gate acting on two spins will maximally entangle them, allowing for deterministic behavior of the circuit. Specifically, I am looking at architectures likely to give rise to novel entanglement behavior, such as circuits in which gates come in sets of “stairs,” with each gate one site to the right of the previous one. The project allows for a mix of analytic and numerical work. While my previous junior paper did include analytic work, I was mainly checking the calculations in one of the papers I was reading. For my thesis I have the opportunity to do new calculations myself and check them in certain limits using the numerics.

The appeal of this project stems from its connection of quantum mechanics to classical mechanics. It takes the system of a quantum circuit and abstracts out some of the quantum mechanics (through the high dimensionality of the spins) while maintaining the ability of the system to demonstrate entanglement. Furthermore, it allows for study of the emergence of information loss, as initially local information eventually gets spread throughout the system so that it is not locally accessible. I have continued to learn lessons along the way, especially in terms of balancing the breadth and depth of my initial research. Professor Huse has helped me in this respect by allowing me to find my own direction but also providing guidance along the way and resources to make sure I do not fall into any ruts.

At Stanford, I want to focus on quantum information and condensed matter systems. Condensed matter theory offers the best opportunity to study the details of quantum mechanics and their connection to other areas of science. Professor Xiaoliang Qi’s research in quantum entanglement and chaos exemplifies the type of research I want to pursue, with its use of methods from quantum information and condensed matter theory and connection to gravity. Other research I am interested in at Stanford include Professor Shoucheng Zhang’s research in quantum spintronics and the quantum spin Hall effect and Professor Steven Kivelson’s work in emergence and spin liquids. I believe that my experience in research and advanced physics classes prepare me well to contribute to one of these groups as a graduate student.

The skills I learn in the course of my doctoral study will improve upon and complement those I have now, making me a productive researcher in the future. I plan to pursue a career in research and teaching, drawing on my academic preparation to contribute meaningfully to the field. My time spent on the cross country and track teams also taught me interpersonal skills that are valuable when working with researchers from different backgrounds. I also hope to be a helpful teacher. This semester I have been tutoring a student in the sophomore mechanics class in an attempt to work on my ability. I know that I would be able to improve all of these skills in a doctoral program at Stanford. Thank you for your time in reading my letter.