Charles Stahl *Stanford University*
Statement of Purpose ***Physics Department***

I love physics because of the fascinating connections that are possible between seemingly distinct topics and courses. I did not understand the breadth and depth of the field until my freshman and sophomore years of college, when my courses in electromagnetism, special relativity, and quantum mechanics emphasized the relationships between seemingly different areas of study: I still remember the incredible lesson that magnetism is a relativistic effect of electric interactions. Just this semester, I had the pleasure of covering symmetry breaking and renormalization in two classes – statistical physics and quantum field theory – in the same two weeks. I look forward to being able to continue my exploration of connections in physics through a PhD program, and Stanford is an ideal location for this study.

Along with lessons in the classroom, I have learned valuable research lessons during my undergraduate career. I started my first independent work, a junior paper entitled "Distinguishing B-Mode Sources in the Cosmic Microwave Background," initially looking to explore a project that was at least partially theory-based. I ended up working with Professor Suzanne Staggs, a cosmology experimentalist, to estimate the power of upcoming cosmic microwave background measurements to constrain early-universe magnetic fields. One exciting connection was the use of spherical harmonics to decompose perturbations in the CMB, a mathematical construct I had so far only seen in the hydrogen wavefunctions. I used 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 not knowing what the code was doing. I was also hesitant to admit when I did not understand important concepts at the beginning of the project, but I resolved to learn from this project to improve in my next junior paper.

In order to make my next semester of independent work more theoretical, I chose to work with Professor Herman Verlinde, a high energy theorist specializing in string theory. Although I would not be able to work directly on his research, he found 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. That project, "Ground States and Entropy of the Supersymmetric SYK Model," gave me the opportunity to choose a new area of research to pursue. The benefits of studying the SYK model included helping me learn about advanced concepts such as quasiparticles and supersymmetry. Supersymmetry was particularly fascinating because it allowed me to focus on an aspect of quantum physics I had not fully appreciated 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 from my previous independent work, I made a point of clearing up my confusions with my advisor early in the project, giving me a stronger understanding of the concepts. 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.

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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, in this case 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 numeric calculations.

The appeal of this project stems from its ability to connect 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 have a path forward at each stage.

If admitted to Stanford, I would be excited 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 on emergence and spin liquids. I believe that my experiences as an undergraduate, including both research and advanced physics classes, prepare me well to contribute to one of these groups as a graduate student.

I know that I would be able to improve all of these skills in a doctoral program at Stanford. 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 look forward to the teaching opportunities that graduate students have. In preparation for this, I have spent this semester tutoring a student in Princeton's sophomore-level mechanics class. The skills I learn over the course of my doctoral study will improve upon and complement the ones that I have now, training me to be a more productive researcher. Thank you for your time in reading my letter.