Statement of Purpose DRAFT. V1. (Columbia)

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Nicholas Quirk

Imagine the dream-like world of the future that we see in so many science-fiction blockbusters and shows. This fantastic vision of the future is what propels me to pursue a Ph.D. in experimental physics. I want to spend my life working on the edge of knowledge; this is an exceptionally exciting time to be alive, and my generation is uniquely poised to make greater technological and scientific achievements than perhaps any before. I am excited by the opportunity to impact the world and help define the scientifically advanced future I dream about.

In 2013, I graduated high school as valedictorian in my home state of New Hampshire. Of several universities that accepted me, I chose to attend Georgetown University in Washington, D.C., because it offers strengths in physics research, and is devoted to public service. Initially, I wanted to work on the policy side of science, and promote new discoveries politically. As I began my physics coursework, however, I found that I really loved studying physics and wanted to learn as much as possible. The Georgetown physics department became my home.

During the second semester of my freshman year, I joined the research group of Prof. Paola Barbara, a group that specializes in nanoscale electronics. I began working on microelectronic devices such as FET’s, p-n junctions, and photodetectors on monolayer graphene. Through my work (over three years) I have gained a breadth of experience and the skills needed to successfully fabricate and analyze custom microelectronics in a clean room environment. The summer after my sophomore year I was awarded the Georgetown Hichwa Family Fellowship to continue my research full-time during the summer. From flexible graphene solar cells built into clothing, to high-capacity graphene batteries with ultrafast charging times for the next era of electric vehicles, the potential applications of graphene seem to be out of a science-fiction dream. This excitement has become the passion that propels me into graduate school.

Although working in graphene microelectronics has been my main research focus at Georgetown, I have also had two other exciting national and international research experiences as an undergraduate: the University of Michigan CERN research semester program, and the Caltech Summer Undergraduate Research Fellowship.

In the fall of 2015, I took a semester off from Georgetown to pursue an internship at CERN, that was arranged and funded by the University of Michigan. I was one of five students accepted nationwide. I worked on the ATLAS Experiment under the mentorship of Professor Richard Teuscher of the University of Toronto. My goal was to understand the response to radiation of new ATLAS semiconductor tracker electronics being designed for the Phase-II upgrade of the LHC (2024). I designed an experiment to irradiate prototypes, cool them to -30oC, and monitor and record their behavior. I designed a graphical user interface to control the electronics during a continuous, eight-day testing campaign. At the end of my internship, I gave presentations to my colleagues and published an Internal Note (10-page document) to the CERN document server of my work for use by the ATLAS Collaboration.

One interesting and unexpected benefit of my work was that with our results we prevented another group from forcing a *shutdown of the LHC* and wasting thousands of dollars. Coinciding with our experimental timeline, one of the subsystems of ATLAS began to have problems with its readout electronics. These electronics were drawing too much current in response to total ionizing radiation, the very same phenomenon that we were investigating with our electronics, which were of a similar design. In short, our results showed that, with *more* radiation, an annealing mechanism would take over in their devices and cause the current increase to diminish. People were anxious to hear our results when we presented them at an ATLAS meeting the day after our testing campaign. The concerned group took our advice to keep their electronics running, and after more exposure to radiation in the LHC, the current returned to safe levels. Working at CERN was amazing; I was able to contribute to a huge collaboration of passionate people designing the most sophisticated experiments in the world to understand the most fundamental questions of the universe.

After my semester at CERN, I submitted a successful project proposal to the Caltech Summer Undergraduate Research Fellowship to work on a new type of on-chip spectrometer being developed by Caltech’s Sub-mm astronomy group for sky-surveys of high-redshift galaxies (summer 2016). My mentor was Dr. C. Matthew Bradford, a scientist at the Jet Propulsion Laboratory. This chip, “SuperSpec,” uses a filterbank of microwave resonators to decompose incident radiation. Each resonator is coupled to a kinetic inductance detector whose coupling strength to a readout transmission line changes when a signal is detected by its attached microwave resonator. I designed and built a system to read out a comb of frequencies on this transmission line and discern the amplitude of the response from each of the resonators on the chip and reconstruct the signal digitally. My system worked effectively for all of our testing purposes, and following my work, the group decided to continue with my system and use it to develop future prototypes of the SuperSpec chips. It was really exciting to be on the forefront of applying new physics to real-world devices to create something that has never been possible before. I was able to become a quasi-expert on this readout system and I acted as a resource for my group during, and after my internship.

In my final year at Georgetown, I am working on a senior honors thesis in graphene terahertz detectors. These detectors employ the hot-electron photothermoelectric effect; photoexcited electrons diffuse across a graphene microstrip, guided by asymmetric contact potentials. My detectors seek greater responsivity than similar devices that have recently been built (e.g., X. Cai, 2014) by exploiting the plasmonic resonance effect in graphene. When the charge carriers in graphene are excited to a resonant frequency dependant on the size of the graphene channel, the response from the photoelectric effect is boosted. With this boost, my detectors should have sensitivities unmatched by detectors that rely on the photothermoelectric effect alone. My devices are currently still in the fabrication phase, but I am excited by their potential results. Furthermore, I have additional experience in CVD graphene growth and transfer methods. I am an associate author on a paper that is in review (2D Materials): *Facile Fabrication of Graphene/MoS2 Heterostructure Devices on Arbitrary Substrates by Photolithography*.

I have recently submitted a proposal to the NSF Graduate Research Fellowship for a project that would extend work I have been doing in Prof. Barbara’s lab into graduate school. Graphene has recently been shown to support population inversion (M. Ryzhii, 2007) and the potential for stimulated emission in the terahertz region. I proposed a project to carry this phenomenon further by exploring terahertz lasers using forward-biased graphene p-i-n junctions to incite population inversion. Such devices could revolutionize terahertz optoelectronics and work to close the so-called “terahertz gap” realized by fields such as astronomy, biomedical science, and more.

I am convinced that Columbia University is the best place for me to continue toward my dream of contributing to the creation of the technologically advanced future. I am especially interested in Prof. Cory Dean’s work in electron optics in graphene p-n junctions. By using similar devices to what I build at Georgetown, Professor Dean’s group has discovered exciting new physical phenomena in graphene. Furthermore, Professor Dean’s group works closely with Professor James Hone of the engineering department, whose work I have studied in depth for my research at Georgetown. With a Ph.D. from Columbia, and the guidance of its expert scientists, I can continue on my way to a career in research and add to the brilliant future I dream about.