Metastasis, or the process in which tumor cells spread and grow from the late stage, primary tumor site to distant, secondary organs, is a significant problem in cancer research today. Metastases have also been shown to cause 90% of all cancer-related deaths, i.e. half-a-million people in the US each year. Detection of circulating tumor cells (CTCs) in whole blood demonstrates that there is a connection between the primary tumor and metastases. Therefore, there is a need to create technologies to enable biological CTC studies. This could contribute to understanding of the spreading of cancer and development of various new drugs and strategies.

As means to isolate these rare cells conventional magnetic activated cell separation (MACS) is carried out at the macroscale, with a large external magnet surrounding a flow channel. This technology uses labeling with antibody-coated magnetic microparticles and extraction by attractive magnetic forces in order to effectively isolate the cells of interest. In recent years, there has been tremendous interest in miniaturizing the MACS process to harness the traditional advantages of microfluidic systems, namely the ability to process microliter-size sample volumes economically and portably. However, recent device designs have typically required large permanent magnets or electromagnets.

These approaches have typically followed an empirical, experimental- and device-centric approach. By contrast, this dissertation represents a “bottom-up” effort to design
a microfluidic MACS system where physical force balance calculations coupled, with measurements of particle and cell parameters, lead to elements of device design. This design includes external magnet design, flow channel layout, and manipulation of multiphase flows. This approach has led directly to a prototype microfluidics MACS system that overcomes the current limitations on external magnetic field sources. In addition, the designed microfluidic platform achieved throughputs better than the state of the art, and efficiencies and purity comparable or better than the standards in separation today.

Concurrent with the rational optimization an effort to investigate the feasibility using magnetic nanoparticle as substitute for the microparticle and sub-micron tags currently used in MACS was conducted. Magnetite (Fe₃O₄) particles were synthesized using traditional thermal decomposition a methods, followed by a ligand exchange using the biocompatible surfactant dopamine. Although it was ultimately determined that labeling with magnetic nanoparticles would required applied magnetic fields beyond the constraints of the mathematical optimization, an interesting increase in magnetic moment was observed following this ligand exchange. Additionally, whilst characterizing the synthesized nanoparticles’ particle diameter and distribution, a novel quantitative evaluation model of the nanoparticle ensemble was outlined solely from temperature-dependent magnetization measurements. These new insights into the characteristics of nanoparticles may allow for better understanding of the synthesized ensembles for implantation in bio-nanotechnological applications.