Research Experience

My research experiences as an undergraduate student introduced me to principles of scientific research and provided a strong skill set in physics and condensed matter. I found my scientific passion during my senior years at the University of Mazandaran, while participating in a NanoBio Materials for Biomedical Applications workshop. I found this new field very fascinating and complex with significance to human health. In addition, my PhD work at Sharif University of Technology introduced me to my primary field of interest, “environmental application of nanomaterials”. My research entailed elucidating the critical role of semiconductor nanostructures for removal of toxic and organic elements for environmental applications. Technically, this project allowed me to develop a strong skill set in physics, chemistry, material science, biotechnology and instrumental analyses, including scanning/transmission electron microscopies (SEM, TEM), atomic force microscopy (AFM), optical spectroscopies, X-ray diffraction (XRD), dynamic light scattering (DLS), Raman spectroscopy, X-ray photoelectron spectroscopy (XPS), and Fourier transform infra-red spectroscopy (FT-IR) in addition to liquid chromatography–mass spectrometry (LC-MS), fluorescence microscopy, flowcytometry assays, antibacterial assay and cell cultures.

After completion of my PhD, I started my Lecturer position at Plasma Physics Research Center, Islamic Azad University in Tehran in 2010 followed by an Assistant Professor of physics at the Department of Physics, University of Mazandaran, Iran, from 2013-2017, where I stablished Nanostructured Materials Research Laboratory. As a Director and Principal Investigator of the lab, my research goals were directed toward overcoming (nano)biotechnology issues for “safe” use of nanotechnology for developing new solar-active nanocomposite materials, new antibacterial materials against resistant bacteria as well as new nanoscale platforms for cancer treatment.

Due to the sanctions and several other issues, I decided to relocate to the US; I started working with Dr. Whitesides at Harvard University as a postdoctoral researcher in Jan 2018. I am currently involved in several different projects including density-based separation using magnetic levitation (MagLev), charge transport across self-assembled monolayers (SAMs), origin of life, and nonlinear materials for soft robots. In addition to my work on MagLev systems, I am merging the fields of magnetism to optics to develop a unique technique for visualization of Lorentz force.

Overall, my experiences have prepared me to pioneer unexplored directions at the intersections of density-based separation using magnetic fields, materials science, and optical imaging systems by applying cutting edge magnetic field design, fabrication, and characterization techniques. I will continue to develop and design specific MagLev platforms to improve separation efficiency and enhance resolution of the system. I will apply fundamental physics and magnetism principles to improve density range, separation time and sensitivity of the MagLev technique; and I will use my background in physics and materials science to ensure that these approaches are reliable and scalable. My lab’s work will enable separation and diagnosis in applications that rely on density, such as biomedicine and also exploring the origin of life on earth. Students and researchers in my laboratory will be trained at the scientific interface between nanotechnology, biomaterials, and medicine through my four-proposed research program summarized below. Ultimately, my goal is to share my experience in science investigation and provide an avenue for students to experience the delight of scientific discovery.

Proposed Research Topics

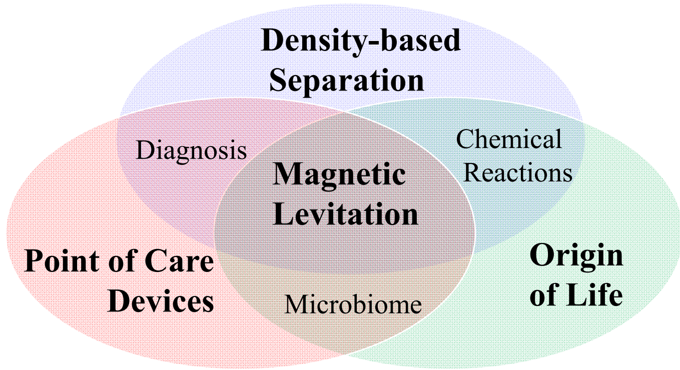

Figure 1. I will develop MagLev technique for separation and diagnosis in applications that rely on density, such as microbiome, biomedicine, materials science, and exploring the origin of life on Earth.

1 - Nitrogen fixation and origin of life

The origin of life on earth is a scientific problem which is poorly understood. There are several hypotheses in this field and one of them was aligned well with my expertise: involvement of electric arc discharge in origins of life. Life on Earth began more than 3 billion years ago, evolving from the most basic of microbes into a dazzling array of complexity over time. But how did the first organisms on the only known home to life in the universe develop from the primordial soup? The growth of all organisms depends on the availability of mineral nutrients, and none is more important than nitrogen, which is required in large amounts as an essential component of proteins, nucleic acids and other cellular constituents. Nitrogen is also found in the nucleus of every living cell as one of the chemical components of DNA. In order for nitrogen to be used for growth it must be "fixed" (combined) in the form of ammonium (NH_4) or nitrate (NO_3) ions. Therefore, nitrogen is often the limiting factor for growth and biomass production in all environments where there is suitable climate and availability of water to support life. In this project we will propose that electric discharge (lightning) could be a plausible solution to this long-standing obstacle of nitrogen fixation on the peribiotic Earth. Miller and Bada have reported that spark discharge experiments form nitric acid in aqueous solution. In this project we will try to show formation of nitrogenous compounds such as ammonia, nitrites, and nitrates as a fixed nitrogen which is a crucial factor in the prebiotic earth and origin of life.

2 - Magnetic Levitation for density-based separation of bacteria in microbiome

The human microbiome is defined as the collection of microbes bacteria, viruses, and single-cell eukaryotes which plays an important role in health spectrum. Researchers are focused on understanding how microbes influence health, disease, and responses to medical treatments which requires new approaches for separation and characterization of biological species. In particular, separations isolate targeted populations of biological components from complex matrices for further analysis. MagLev is a physical technique which works based on the density of objects as a universal physical property of all materials. This is a simple, inexpensive, compatible, and functional technique which enables us to solve a broad range of problems in physics, chemistry, and biology. Density is conveniently accessible, helpful in separation (densities are different for DNA/RNA (~2.0 g/cm^3), viruses (1.2-1.5 g/cm^3), bacteria (1.08-1.10 g/cm^3), and mammalian cells (~1.05 g/cm^3)) and in providing useful fingerprinting and patterns; it is more accessible and faster than techniques that are widely used to carry out separations, such as ultracentrifugation and therefore potentially useful in hospital practice. We first try to start with two types of *E. coli* and *Staphylococcus* aureus bacteria as representative of gram-negative and gram-positive bacteria then will extend separation to a more number of bacteria relevant to microbiota. We think cells of different types or states have unique magnetic and density signatures, which can be levitated in a predictable way when they encounter a magnetic field. In the proposed research we will use MagLev method for separations of different types of bacteria available in gut microbiome. The basic chemistry and physics of these separations has been partially prototyped, but not fully developed; these methods are just beginning to be applied to biological problems.

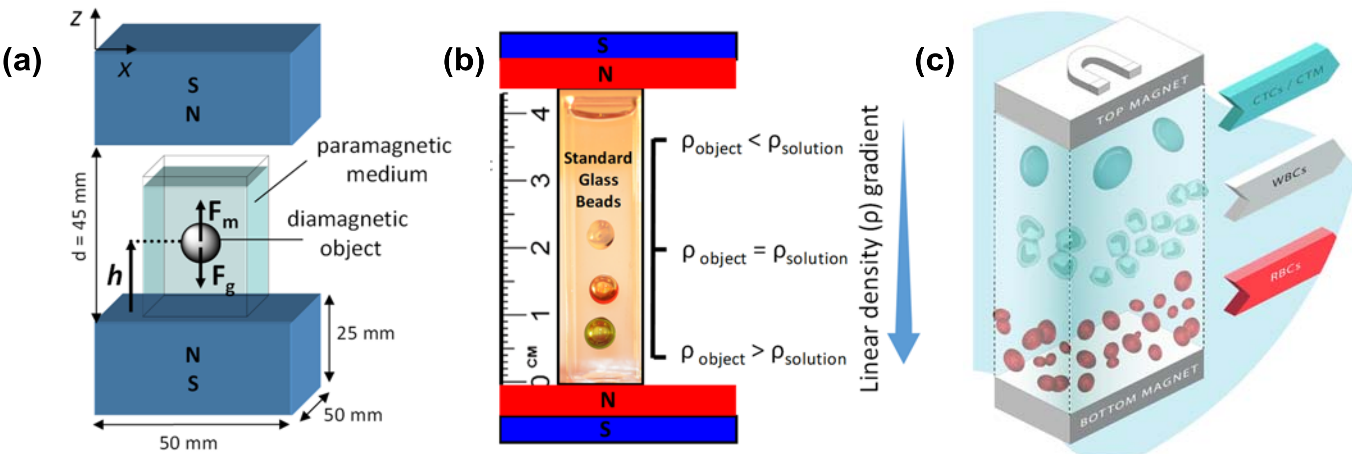

Figure 2. (a) Principles of MagLev technique, (b) and (c) density-based separation of diamagnetic materials.

3 - Magnetic Levitation for point of care (POC) blood infection diagnosis

The striking prevalence of various diseases such as HIV, tuberculosis and malaria, as well as outbreaks of emerging infectious diseases, such as influenza A (H7N9), Ebola and MERS, poses great challenges for patient care in resource-limited settings. However, advanced diagnostic technologies cannot be implemented in such setting largely due to economic constraints. Simple and inexpensive point-of-care (POC) diagnostics, which rely less on environmental context and operator training, have therefore been extensively studied to achieve early diagnosis and treatment monitoring in non-laboratory settings. Despite great input from material science, biomedical engineering and nanotechnology for developing POC diagnostics, significant technical challenges are yet to be overcome. In this regard, Maglev is a label-free, sensitive, and specific testing platform using very small amount of blood sample (<1 μl) based on the difference in density of bacteria in blood. Accurate diagnosis of bacterial infection is crucial to avoid unnecessary antibiotic use and to focus appropriate therapy. One of the greatest issues of our time is antibacterial resistance and the challenge is to create a cost-effective, accurate, rapid and easy-to-use test for bacterial infections. Clearly, this is a very important problem that has yet to be fully solved. In this regard, a small portable MagLev system will be designed and installed on smartphone. This miniaturized MagLev platform includes a pair of small bar magnets and a microcapillary glass tube in between which is filled by blood sample and paramagnetic solution. Commercially available inexpensive plug and play USB microscope camera will be used to capture the image. Blood sample will be levitated in the magnetic field based on equilibrium between the magnetic and gravitational forces acting on the cells. Using this approach, we are able to distinguish between the levitation patterns of infected blood by bacteria versus control blood sample based on their levitation patterns.

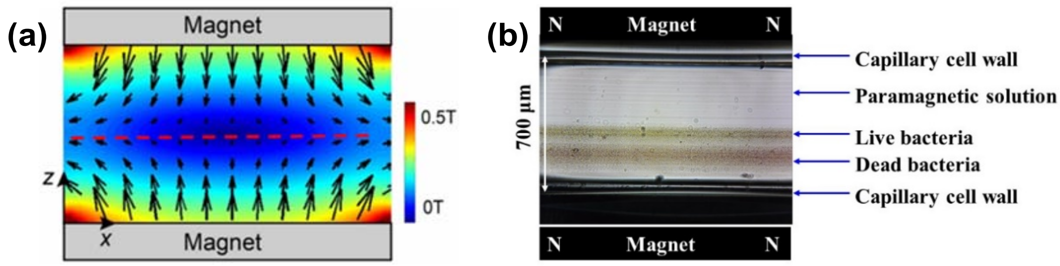

Figure 3. (a) Miniaturized MagLev platform for POC diagnosis and (b) separation of biological species.

4 - Magnetic Levitation to monitor the kinetics of chemical reactions of shape selected nanostructures

MagLev can also be used to monitor the kinetics of chemical reactions of shape selective nanostructures. The main aim here is to show the changes in density upon formation of hollow nanostructures. When an aqueous suspension of silver nanocubes is titrated with an aqueous solution of $HAuCl_4$, the galvanic replacement reaction between these two species occurs immediately, leading to the formation of gold-based nanoboxes and eventually nanocages. This method has been successfully applied to prepare gold-based hollow nanostructures with a wide range of different morphologies. These hollow and porous metal nanostructures show particular crystalline and geometric structure, mechanical properties and consequently density in nanoscale. Formation of gold nanocages from silver nanocubes results in a large change in density when galvanic replacement reaction occurs. We expect MagLev would be able to show formation of Au nanocages and monitoring of kinetic of the reaction which introduces a new tool to chemistry and materials scientists which complements other available analytical techniques.

Supplies, Equipment, and Funding

The research topics I proposed above require equipment readily available in most physics, chemistry, materials science, and biomedical engineering departments. The equipment includes XRD, UV-Vis, Raman, FTIR, XPS, DLS, SEM, TEM, AFM, confocal, fluorescent, and cell culture facilities. In order to enhance my research program, I plan to either secure external funds or use part of a startup package to purchase some new instruments which may not be available on-campus. A reasonable startup package will be sufficient for purchasing necessary reagents and minor equipment. In addition to my startup fund, I am dedicated to continually working towards obtaining external grants for independent and collaborative projects, including the SNF, and NIH (more specifically R and K series).