Gas Phase Polymerization and Nucleation Experiments in Microgravity

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The proposed research is focused on two categories namely, gas phase/aerosol droplets polymerization and vapor to liquid homogeneous nucleation. Understanding the fundamental mechanisms that govern polymerization reactions is an important question in a number of scientific disciplines as well as practical applications. Despite the fact that solutions and bulk liquids are the preferred medium for many industrial and laboratory polymerization processes, our fundamental understanding of the polymerization reactions in solution remains limited. Under normal circumstances, polymerization is conducted in condensed systems (monomer liquid or solution) in which multiple reactions (initiation, propagation, chain transfer, termination, etc.) are occurring simultaneously. Information regarding the exact nature of each mechanistic step and understanding of elementary events occurring in the course of polymerization remain largely unavailable. In solution the problem is further complicated by reaction within the solvent. In cationic polymerization, the very high reactivity of cationic monomers cause the reaction rates to be unmeasurably fast, thus obscuring the kinetic and mechanistic details. Furthermore, cationic polymerization often stops before complete monomer consumption since the ion pair eventually recombines and terminates the process.

One of the major goals of the proposed work is to demonstrate the application of gas phase polymerization, in ground-based experiments and eventually in microgravity, for the synthesis of unique polymeric materials. The proposed research involves polymerization in a neat monomer vapor or a mixture of two monomers, or in monomer droplets suspended in the vapor phase. The droplet polymerization method involves the use of nucleation (of liquid droplets of monomer) for the synthesis of large polymer molecules and for the study of their chemical and physical properties. Under earthbound conditions, the size of droplets suspended in nucleation chambers is limited to microns, since larger droplets settle from the nucleation volume. Processes in larger droplets may involve a fundamentally different balance of surface vs. bulk forces and compositions, and intra-droplet convection and mixing phenomena. These conditions can affect the chemistry of propagation and termination of large polymer chains and also the properties of the resulting materials. The new process of intra-droplet polymerization will be analogous to suspension polymerization in solution, which has major industrial applications. Without gravitational settling, the monomer droplets can grow to large sizes, and polymerization in these droplets can lead to large polymer particles with a uniform size distribution. With large aerosol particles, polymer growth will be limited by factors other than gravitational settling, such as radical recombination, similar to termination in emulsion polymerization. The comparison of polymerization in emulsion micelles vs. aerosol droplets can contribute significantly to the fundamental understanding of both processes.

The proposed research will benefit the development of microgravity polymerization technology by providing, for the first time, a feasibility study which will determine the relevant physical and chemical processes involved in gas phase and suspended droplets polymerization. In addition, the potential for growing high quality polymeric materials with novel properties using solvent-free polymerization in microgravity will be demonstrated.

Nucleation is one of the most ubiquitous and important phenomena in science and technology. The nucleus for homogeneous nucleation remains one of the most elusive entities known in chemical physics, and has never been observed directly. Only the consequences of its presence, e.g. droplet formation, precipitation, etc. are observed. The typical measurements of vapor to liquid nucleation rates involve light scattering from liquid droplets that fall, under the influence of gravity, from the supersaturated vapors. One of the very important current issues in nucleation research is whether the observed effect of a carrier gas is due to convection and instability in the operating conditions of the nucleation chamber under 1-g or if it actually represents a real contribution to the nucleation process. There is no other way to answer this question except by complete elimination of the convection and other instability conditions by carrying out the nucleation experiments in microgravity. The growth of nuclei in supersaturated vapors under microgravity conditions is expected to provide a more accurate and reliable picture of the growth process that can now be used to test the validity of different nucleation theories. This is the second objective of the proposed research.

This multi-disciplinary project that combines polymerization and nucleation from the vapor phase is expected to have a significant impact on these and related fields.