2. Overview/Abstract

Freezing of water leading to ice crystal growth and frosting endangers commercial and military equipment as well as critical biological tissues and materials. To combat the effects of freezing, a variety of anti-icing and de-icing agents, antifreeze surface coatings, and cryoprotective agents have been developed. These synthetic antifreeze agents are, unfortunately, far less efficient than biogenic antifreeze agents that allow diverse species to survive in sub-freezing temperatures. Natural antifreeze proteins, for example, represent a promising class of biopolymers for use as cryopreservation agents and as antifreeze coatings. The limited quantities and high production cost of antifreeze proteins and being susceptible to degradation, however, limit their widespread adoption as alternatives to synthetic antifreeze agents. In an effort to develop more efficient antifreeze agents, there is a need to develop rational strategies for mimicking antifreeze proteins and to understand how these biomimetic antifreeze agents impact ice nucleation and freezing of water droplets.

The overall goal for this proposed research project is to derive, from well-defined biomimetic molecules and surfaces, principles for the rational design of anti-freeze molecules and coatings. An improved ability to control the mechanisms underlying icing of surfaces or tissues will directly benefit society, through the design of future aerospace vehicles, naval equipment, infrastructure, food storage solutions, and cryopreservation of cells and tissues. To accomplish this goal, we will (1) develop peptide-polymer conjugates that interfere with ice nucleation in solution by mimicking a new class of antifreeze proteins (i.e., β-helical antifreeze proteins), (2) establish relationships between the structures of bioinspired polymer brush surfaces and their antifreeze properties, and (3) investigate surfaces that mimic non-ice-binding regions of β-helical antifreeze proteins. The first goal of the proposal will focus on rationally designed synthetic polymers that mimic the ice-binding features of natural antifreeze proteins required to destabilize ice by altering the size and shape of the ice crystals. The other goals of the proposal will explore surface coatings that depress the freezing temperature of water by mimicking features of natural antifreeze proteins that disorder water molecules near the surface of the protein. The proposed research goals fully integrate the expertise of the collaborating PIs: the peptide design and synthesis capabilities of the Rudick lab; polymer chemistry of the Grubbs group; the microscopic and kinetic freezing measurement expertise of the Knopf group; and, the experience of the Laughlin group developing assays to understand the molecular mechanisms of zebrafish biology.

Application of a multidisciplinary approach that combines synthetic, materials, biological, and physical chemistry will generate unique and transformative data. The proposed research will provide fundamental solutions on the governing parameters that make molecules and coatings act as ice inhibitors, thereby paving the way to enable applied technologies for efficient antifreeze agents. The expected outcomes of this project will be a major advancement in the fundamental understanding of how novel synthetic, antifreeze molecules impact the ice formation processes in solution and at solid-liquid interfaces.