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Understanding Heterogeneous Ice Nucleation: A Cryobiological Perspective

The formation of ice is a key process through much of cryobiology. The temperature at which ice forms in controlled rate freezing systems is an important determinant of survival rates for many cell types and avoidance of ice formation is vital for vitrification processes. All ice formation, in any system, must be preceded by a nucleation event. While homogenous ice nucleation, which occurs in the absence of a heterogeneous ice nucleator, is well understood very few, if any, cryobiological systems will nucleate homogeneously due to the presence of biological entities and container surfaces. Heterogeneous ice nucleation, which dominates in the vast majority of systems relevant to cryobiology, is not well understood at current. Indeed, the identity of the nucleators responsible for ice nucleation in most systems is not known. As a result, predicting the temperature and rate at which nucleation will occur in any given system is very difficult.

Recently, the relationships between physical and chemical properties of nucleators and their ice nucleating abilities have been extensively studied by experimental and computational means and understanding is steadily improving. The motivation for much of this research has been to improve understanding of atmospherically relevant ice nucleators. However, knowledge gained is potentially applicable to cryobiological science as well.

Here, various aspects of these recent advances are outlined and discussed, along with their relevance to cryobiology. For instance, it has been shown that various cryoprotectant molecules can have significant and unpredictable impacts on ice nucleation temperatures, with both enhancements and suppressions of ice nucleation observed. These effects have the potential to influence outcomes of cryopreservation procedures. Similarly, progress has been made in understanding why certain minerals and biological entities nucleate ice efficiently. This knowledge may allow us to understand and control ice nucleation in cryobiological systems and thereby improve outcomes.