Vitrification in physics, cryobiology, and cryonics

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- **Cryobiology is the study of the effects of freezing and low temperatures on living systems.**
- **Nature has had millions of years to adapt living organisms to the stress of low temperature.**

- **Cryobiology tries to understand how nature has reconciled the physical and biological principles for surviving organisms at low temperature.**

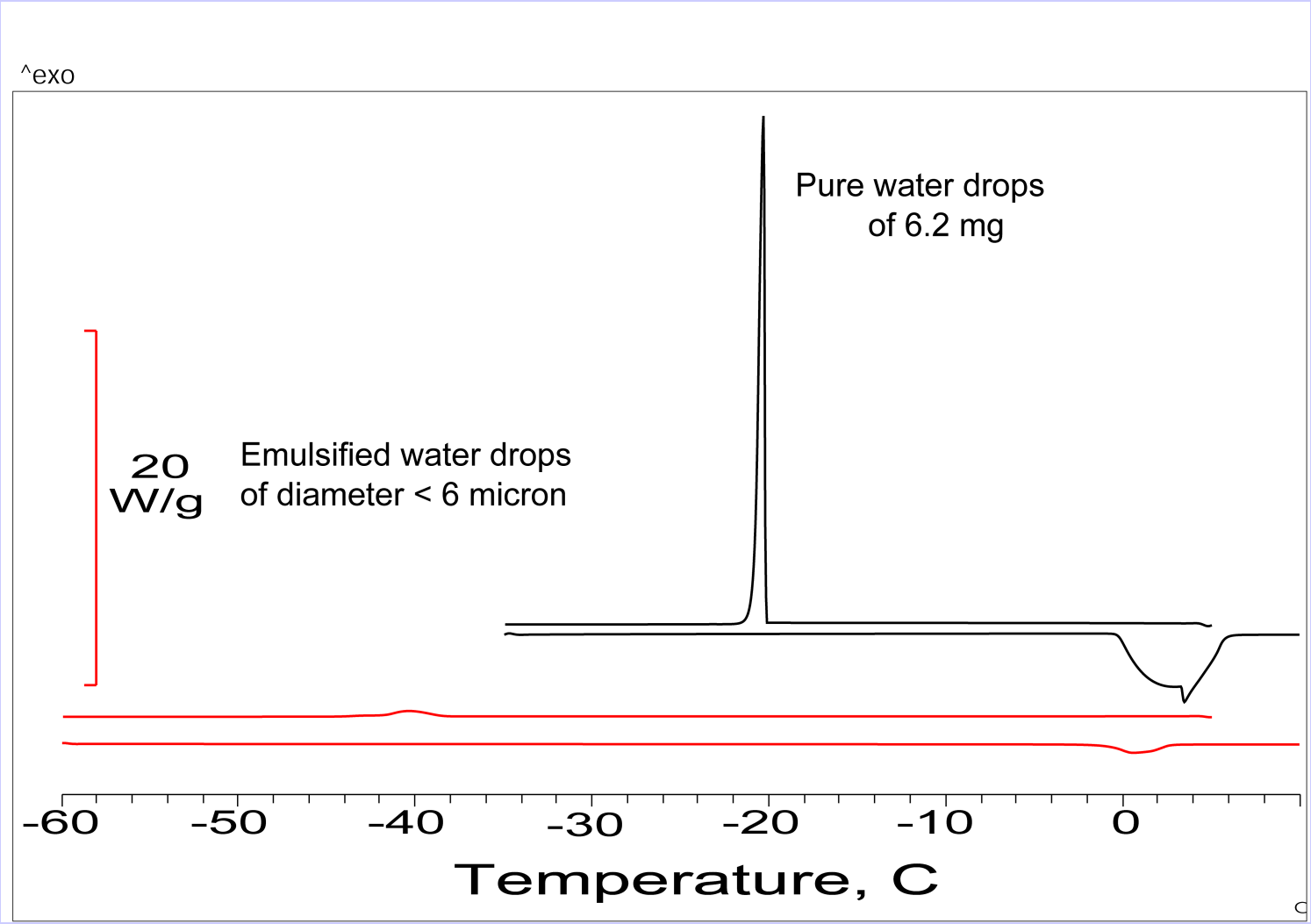
- **Cryonics is the preservation of legally dead humans or pets at liquid nitrogen temperature in the hope that future science can restore them to life.**

- **Cryobiology and cryonics stand at the interface between physics and biology.**

Vitrification in physics

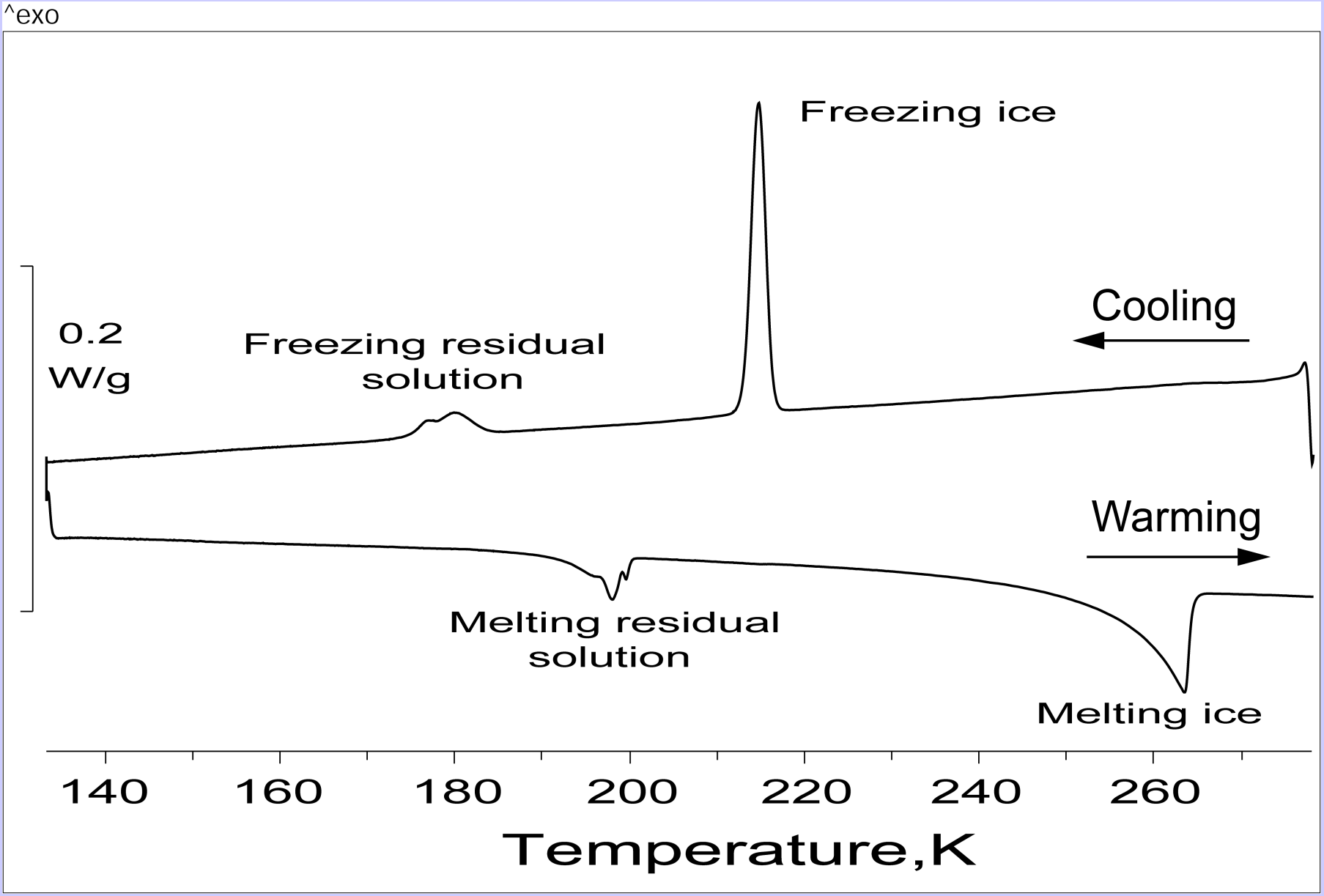
Calorimetric study

Freezing temperature of pure water drops depends on size

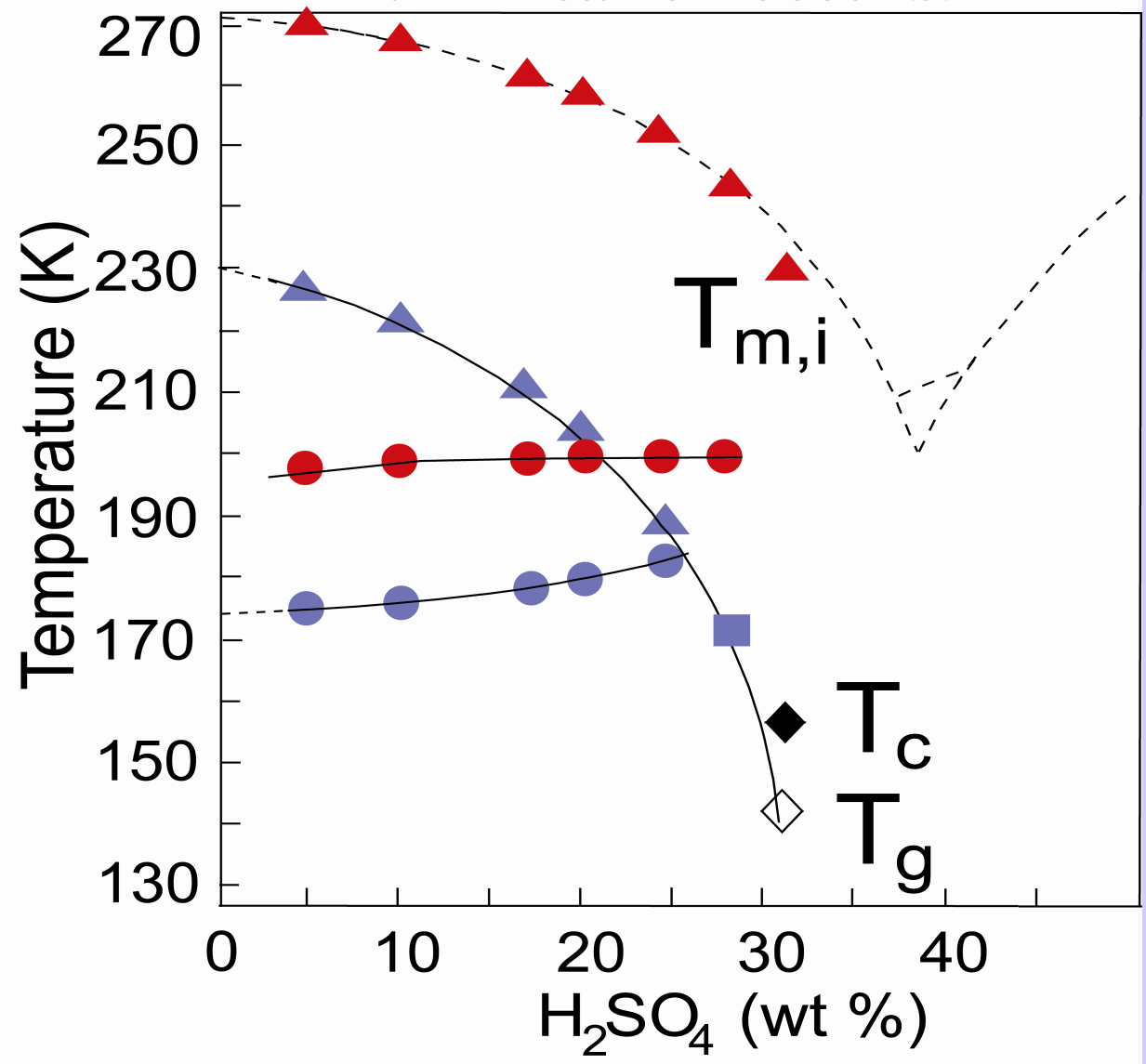


Addition of solutes to water additionally reduces freezing temperature

Example of calorimetric curves of the freezing, phase separation, and melting of emulsified solution drops



Example showing how increasing concentration of solute (H_2SO_4) reduces freezing temperature until vitrification occurs.



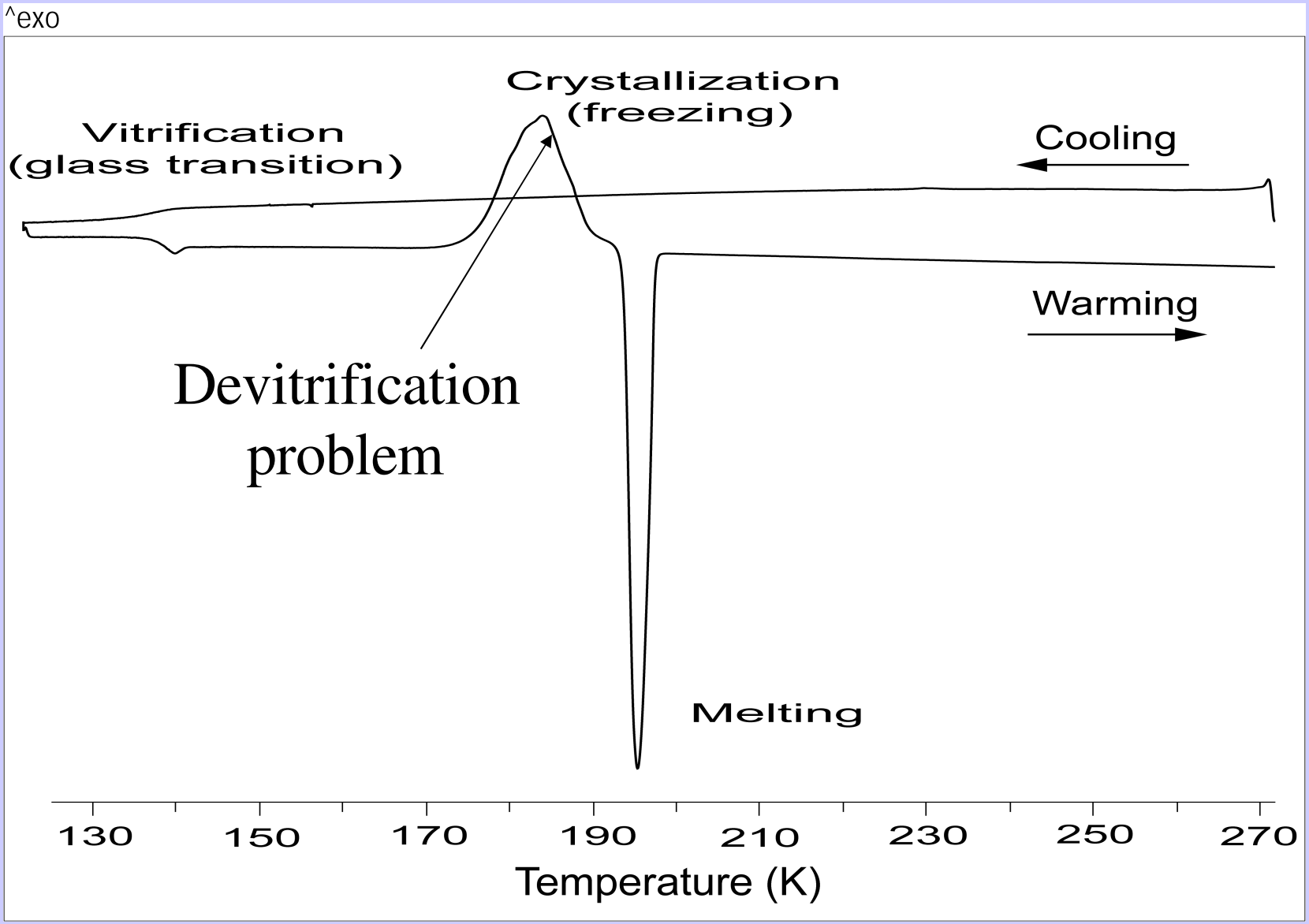
- **Vitrification is a process of converting aqueous solutions into the glassy (amorphous) state on cooling escaping freezing. The formation of ice is prevented by:**
  - **very rapid cooling rate**
  - **the introduction of some agents that suppress the formation of ice.**

Additives, which are used in cryobiology and cryonics or produced naturally by organisms, are called cryoprotectants.

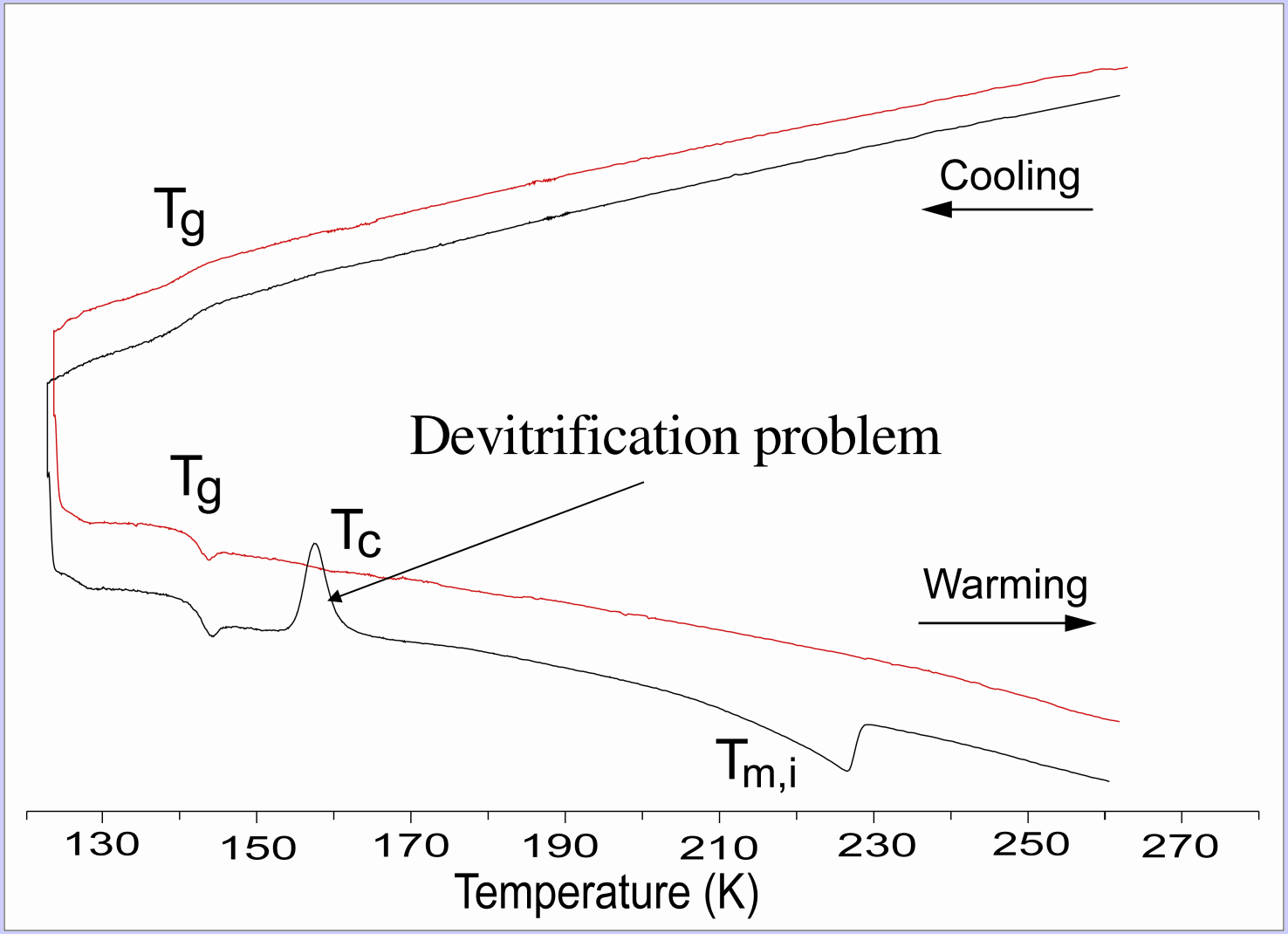
- **Polar fishes and insects make "antifreeze" proteins (ice blockers) which prevent:**
  - **the nucleation of ice ;**
  - **the growth of the already formed ice**

within the insect which is below its freezing temperature.

Example of cooling sample without freezing. Crystallization (freezing) and melting occur on warming

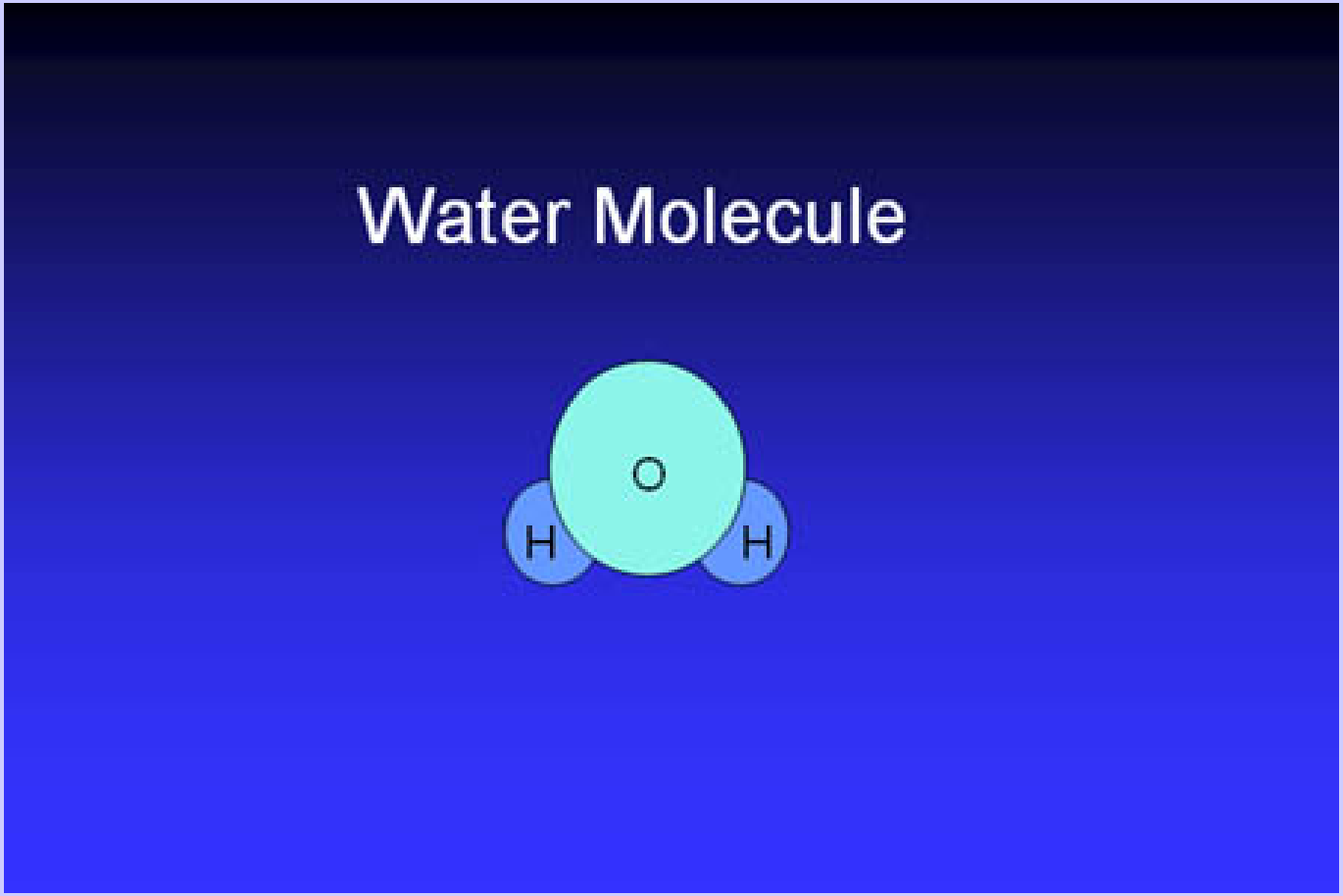


Pure (black curves) and seeded (red curves) with fumed silica (SiO_2) emulsified solutions behave differently at low temperature



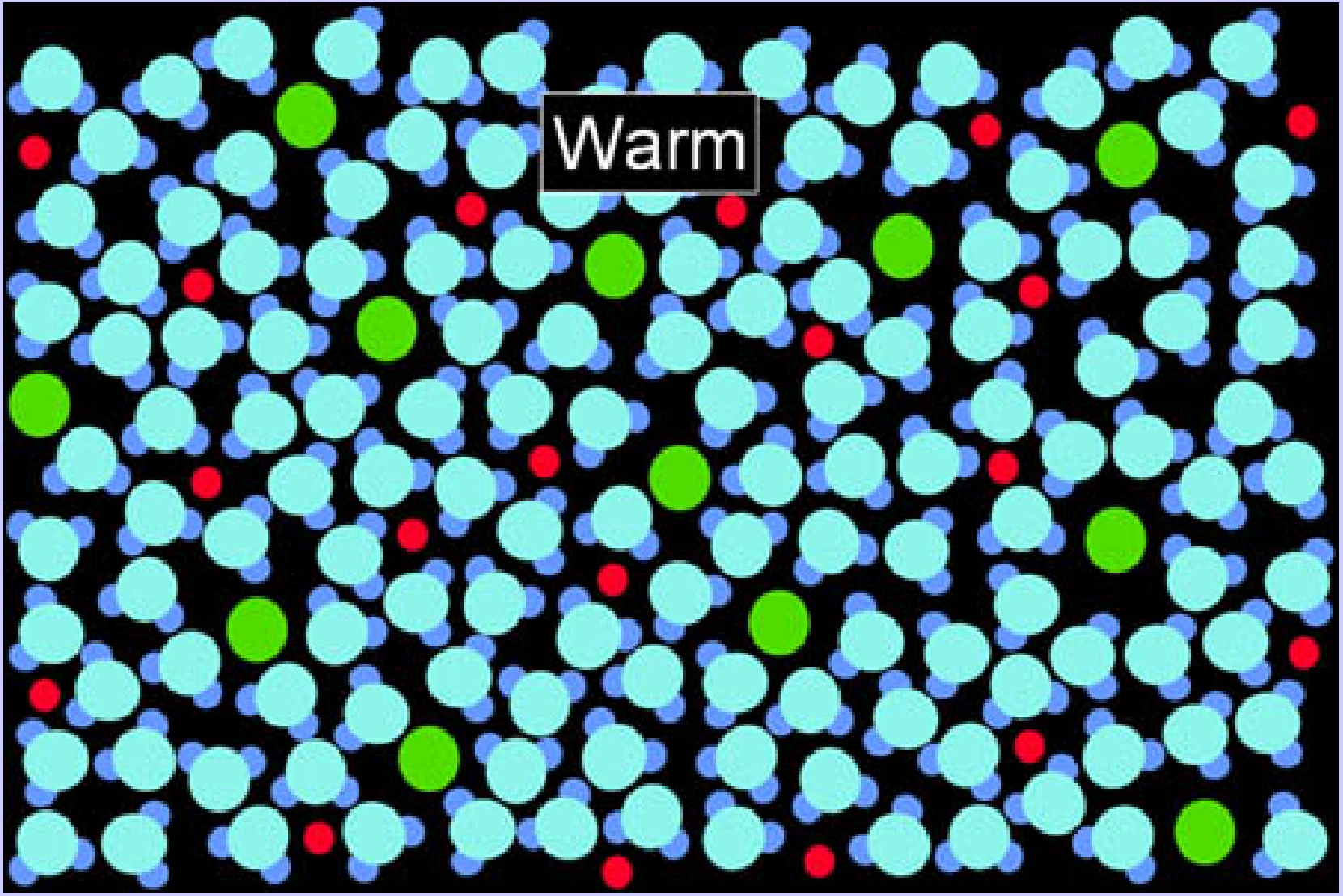
Vitrification in biological systems

1) Living tissue contains much of water:

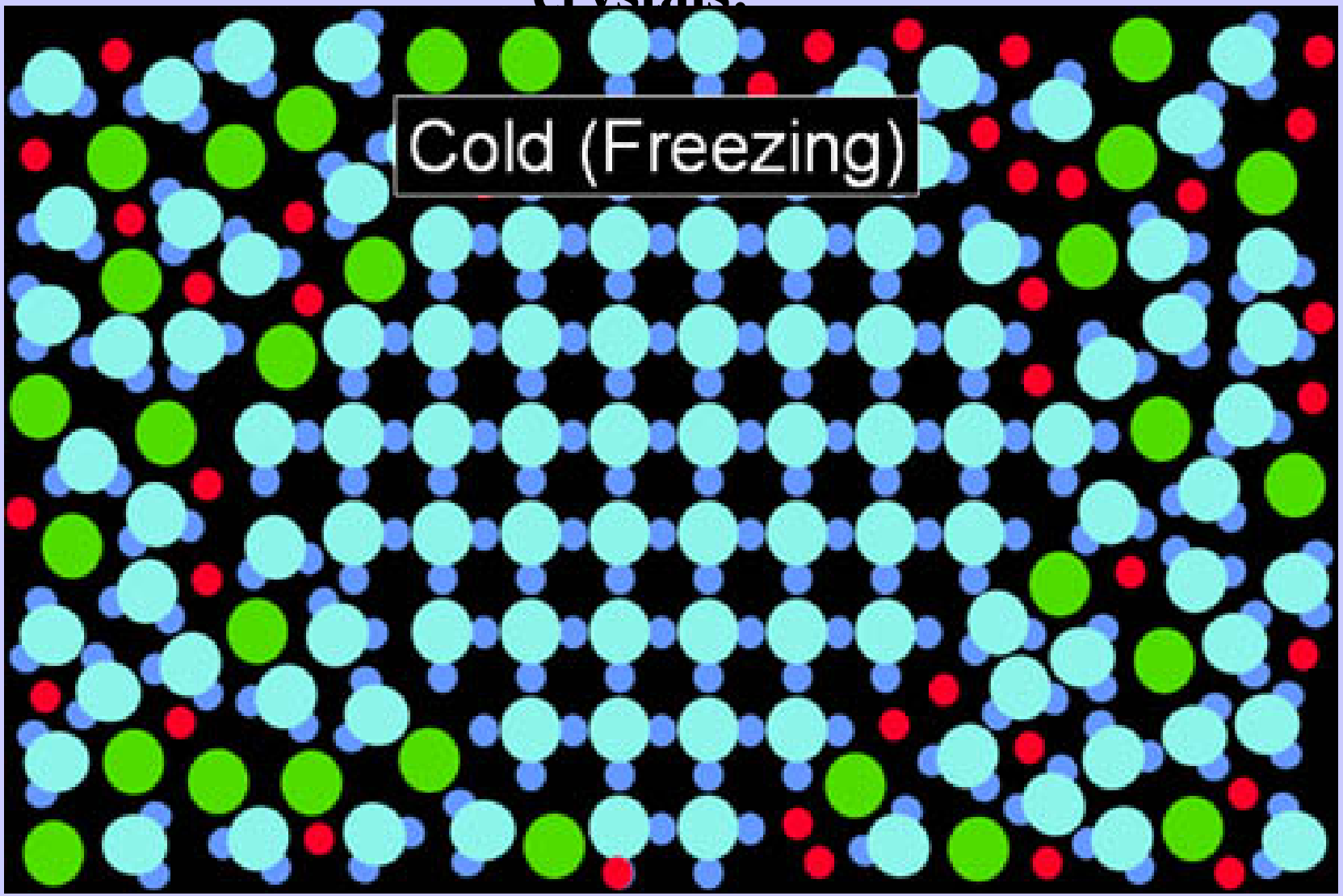


From:
http://www.alcor.org/Library/html/vitrification.html
with changes

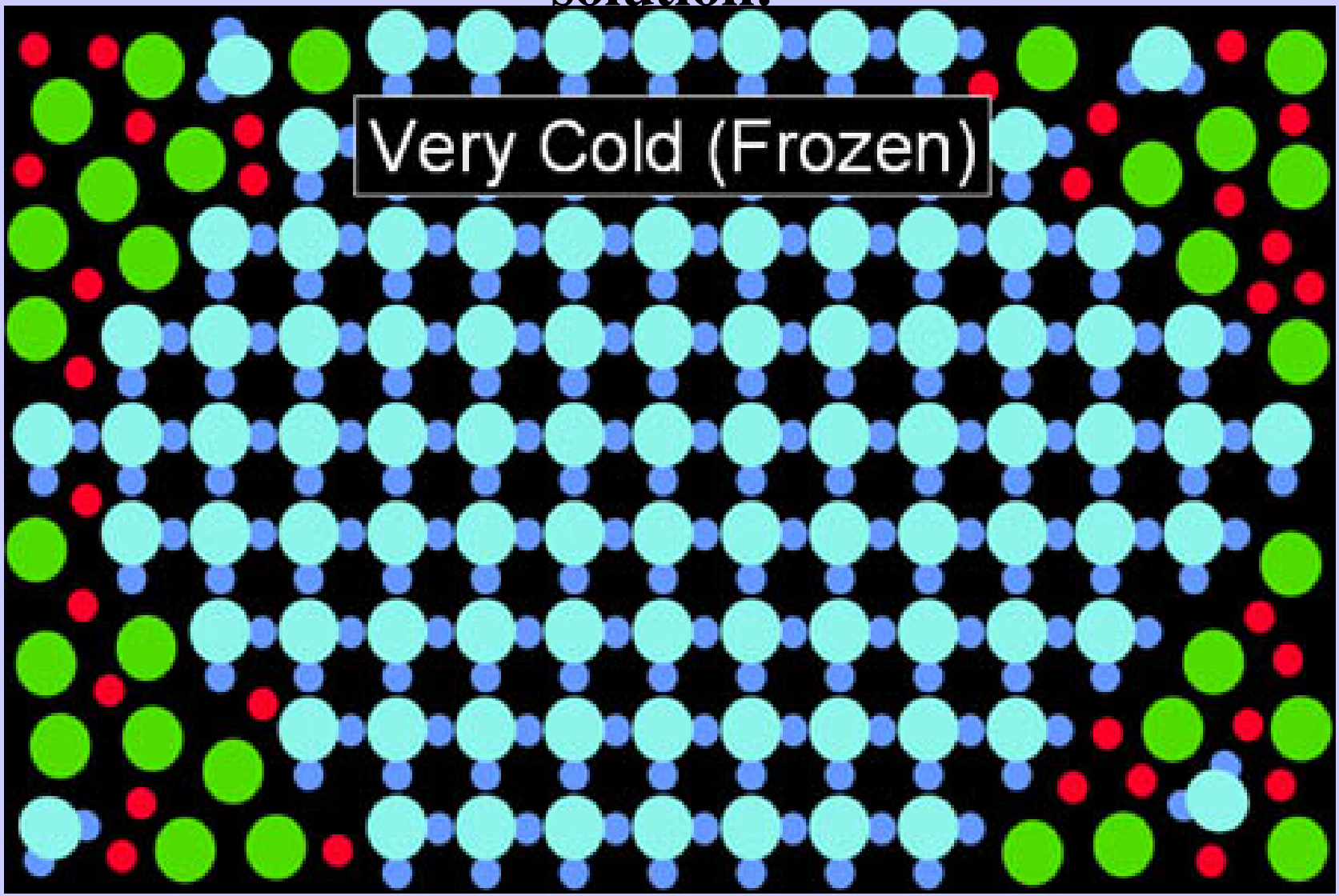
2) Water is component of a cellular solution in living tissue



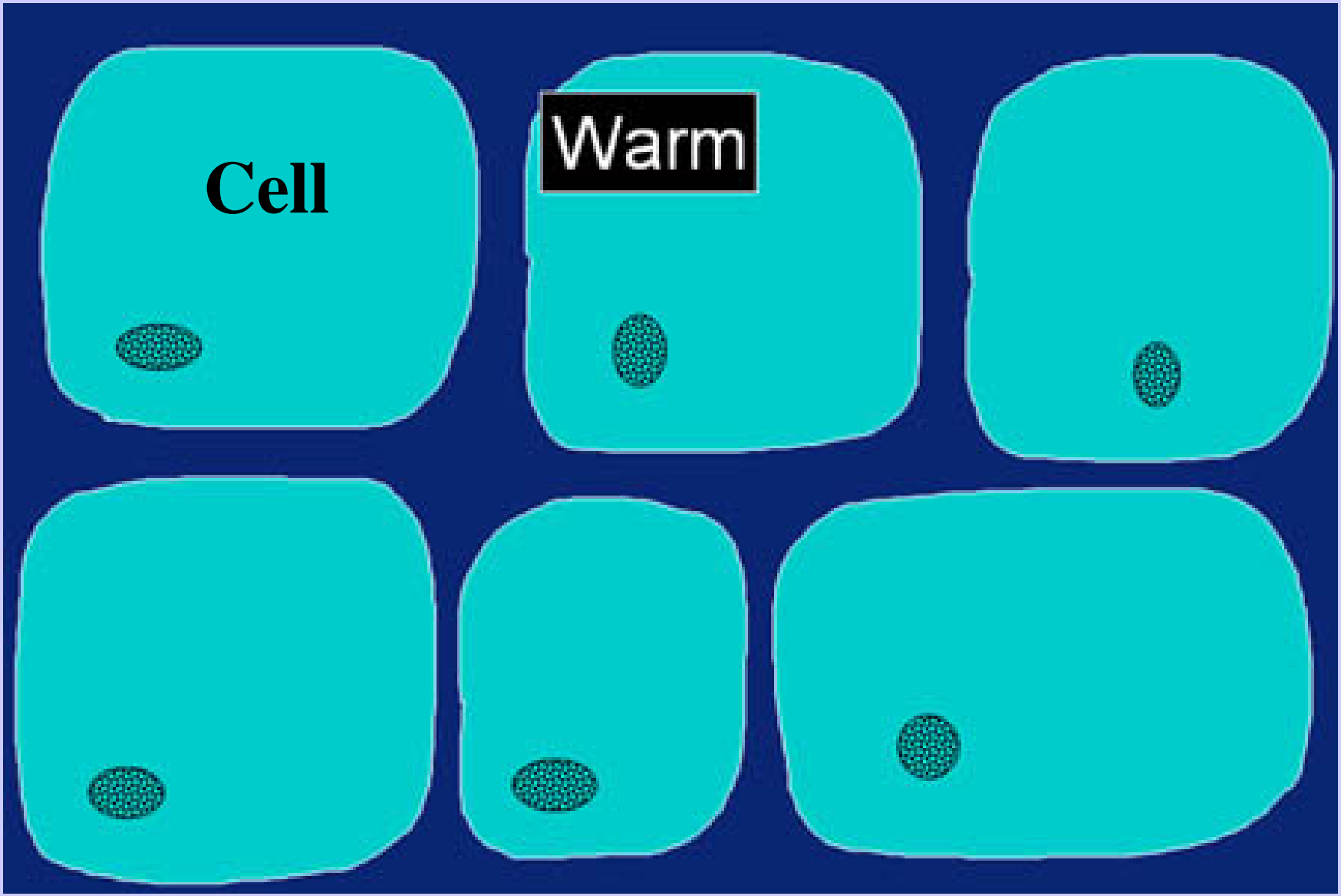
3) When tissue is cooled below freezing temperature, water molecules gather together and form growing ice crystals:



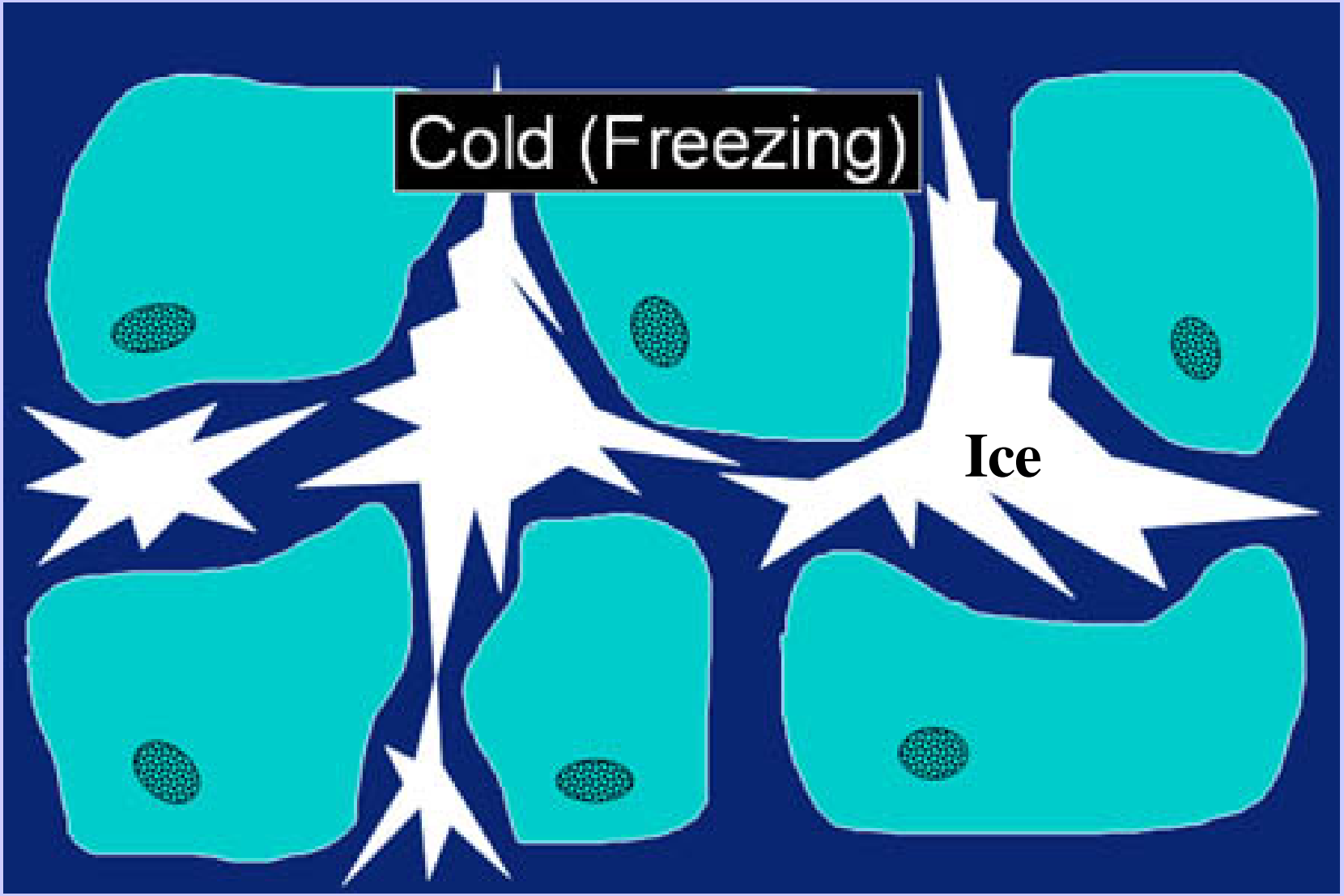
4) Growing ice expel other molecules from the ice lattice to form a harmful concentrated solution:



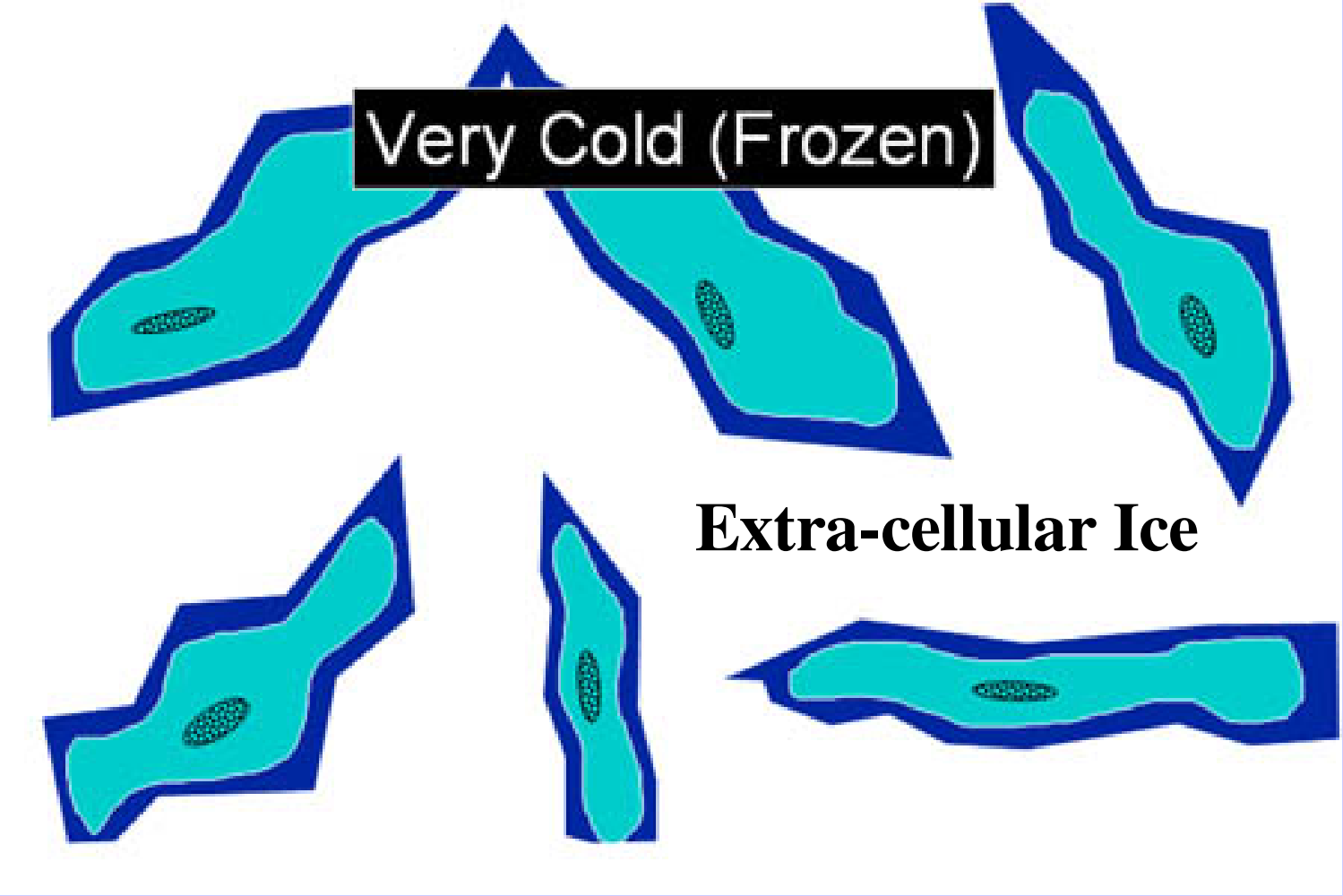
5) On a cellular scale, ice forms first outside cells:



6) Growing ice causes cells to dehydrate and shrink:



7) Finally cells are left damaged and squashed between ice crystals. The damage is mostly mechanical.



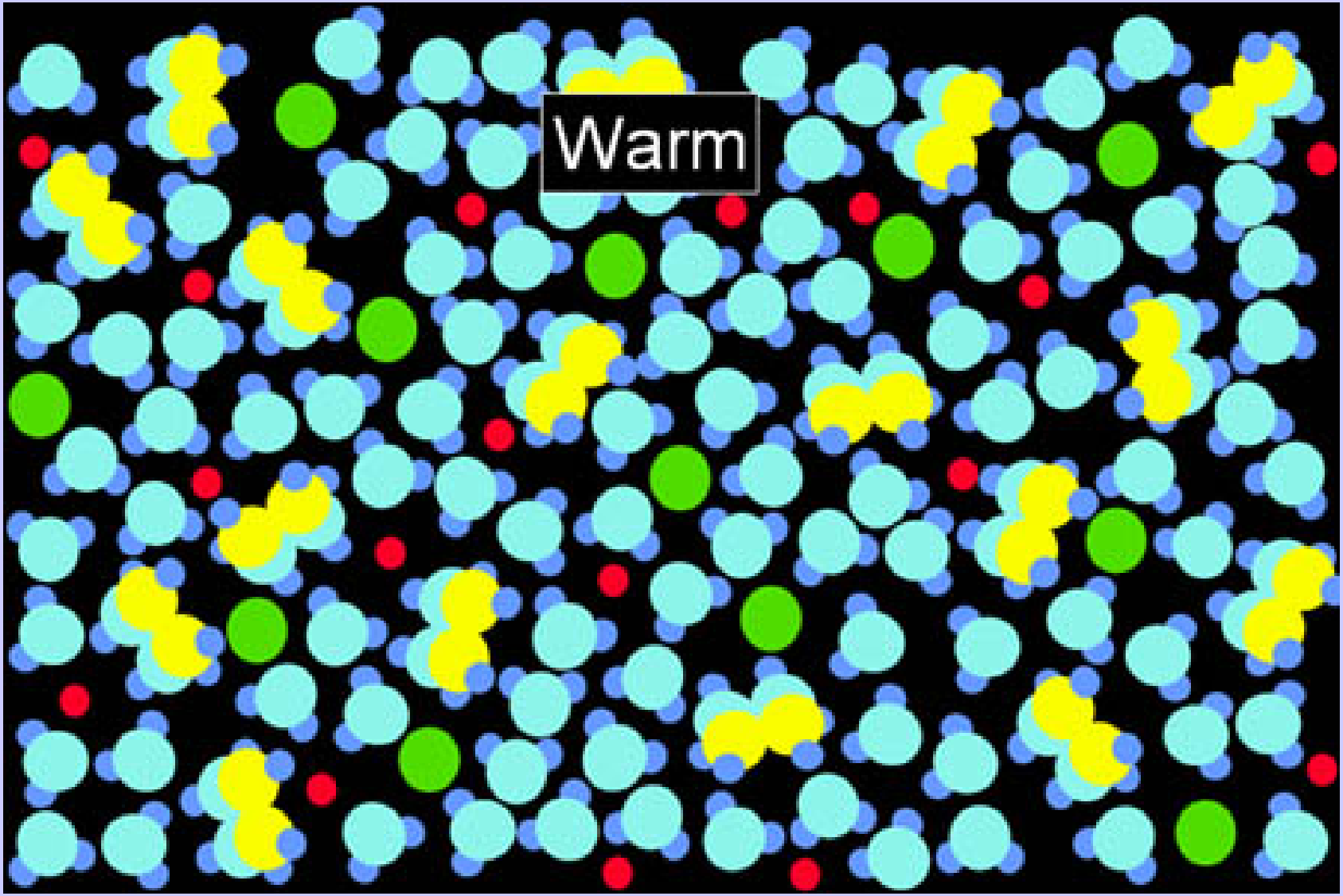
How to prevent the formation of ice?

- **Glycerol and sugar glucose are natural cryoprotectants.**

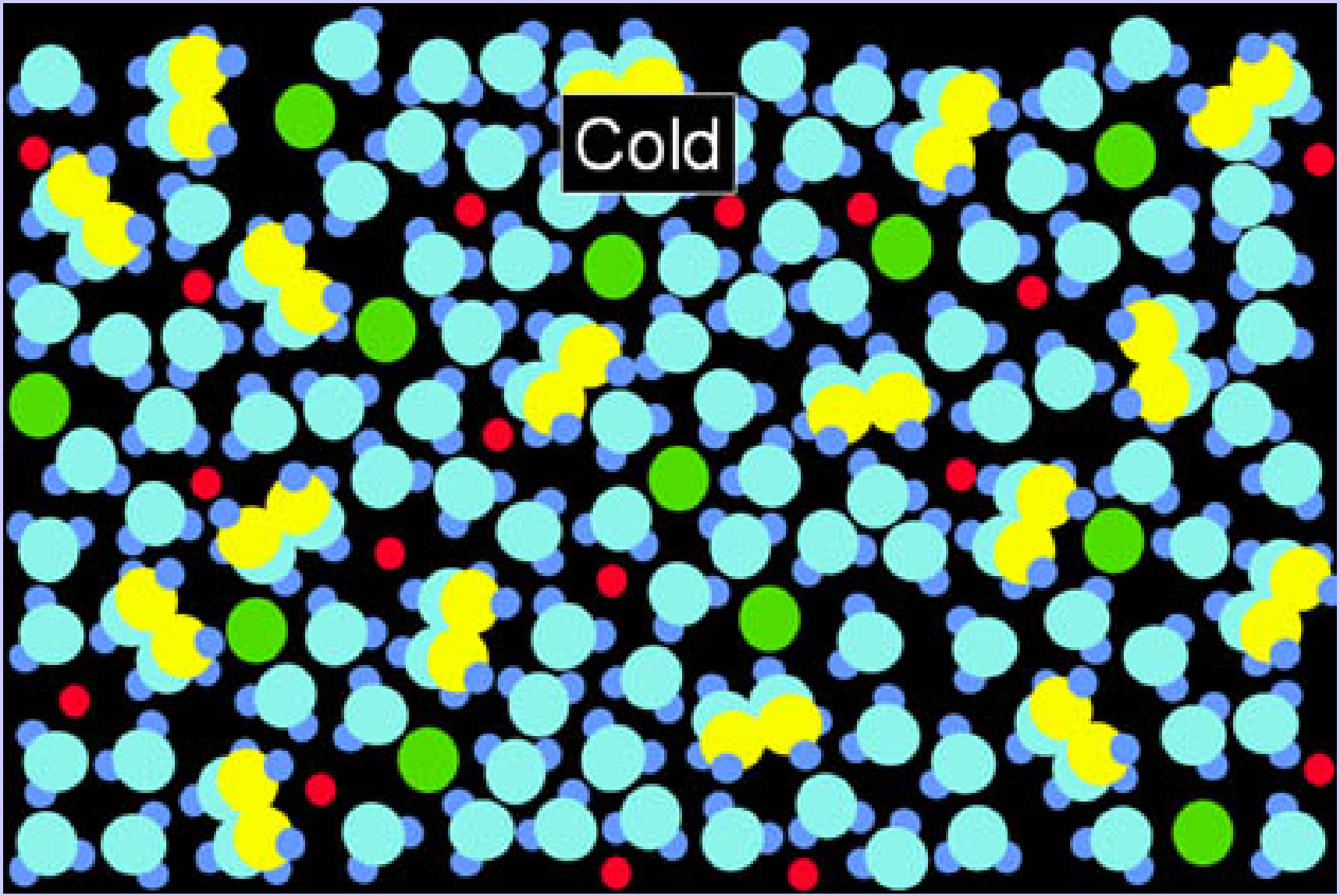
- **There a number of synthetic cryoprotectants.**

- **Concentrated cryprotectants are toxic.**

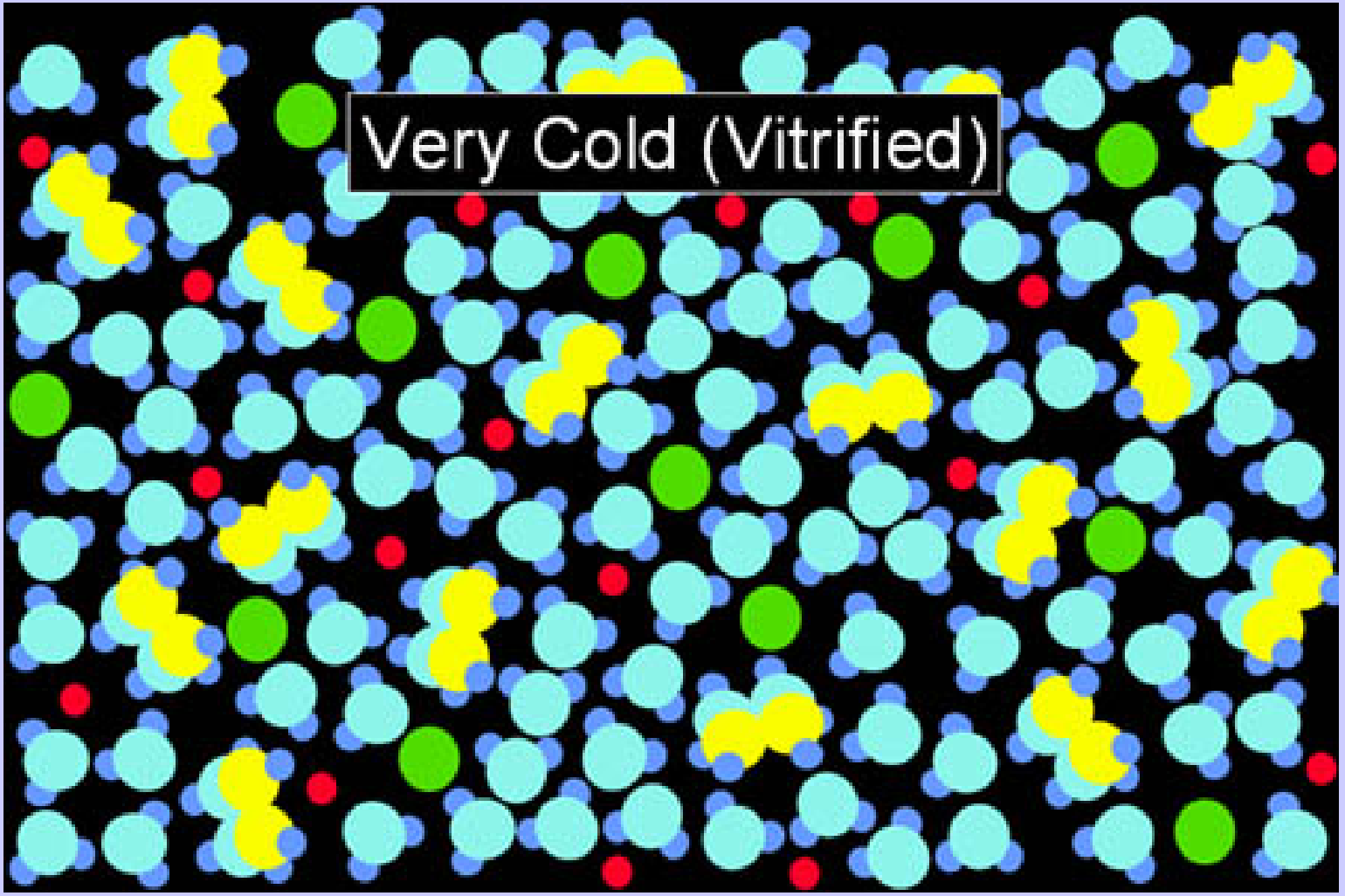
8) Adding cryoprotectants to cellular solution can prevent crystallization of water to ice:



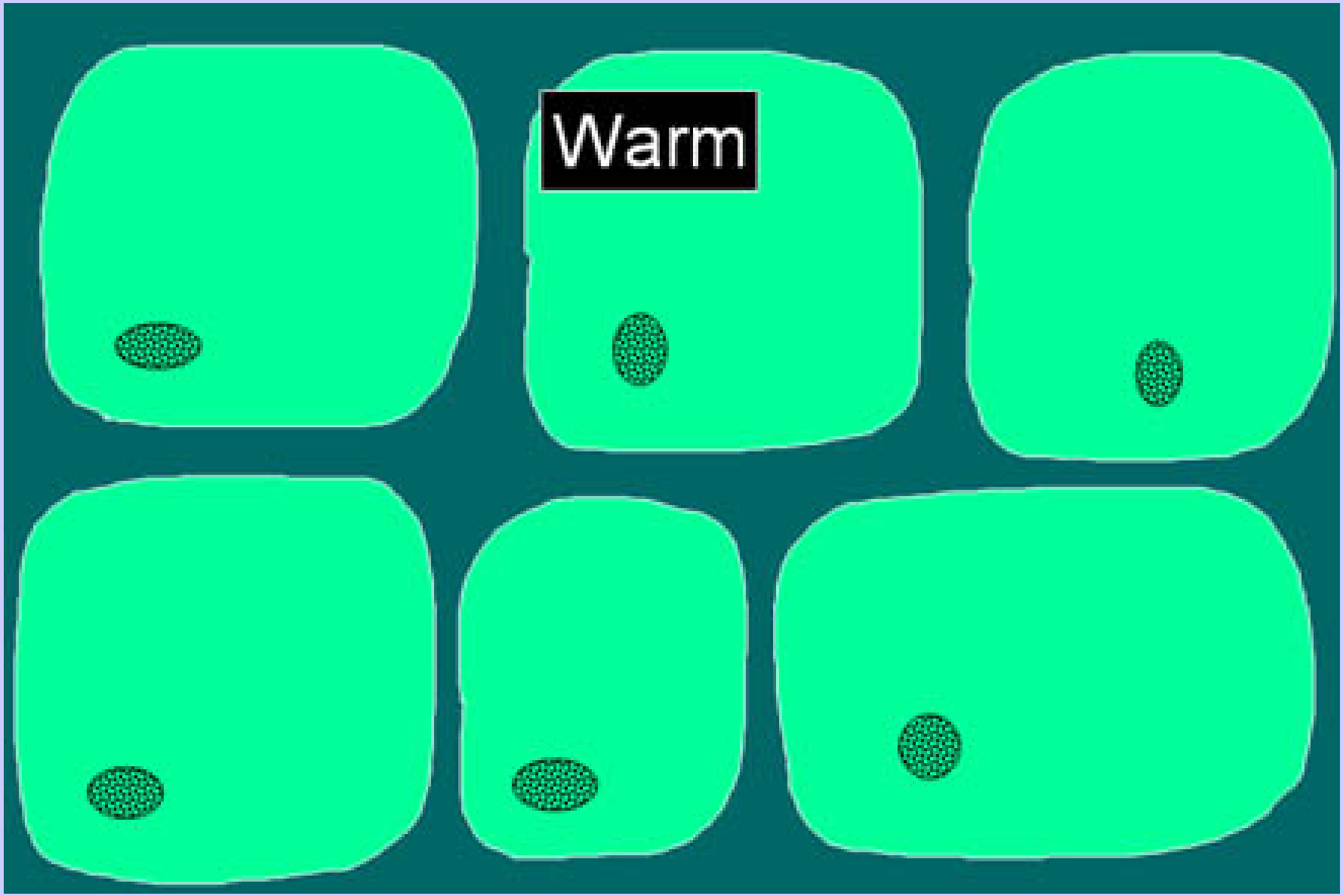
9) Instead of freezing, molecules just move slower and slower as they are cooled:



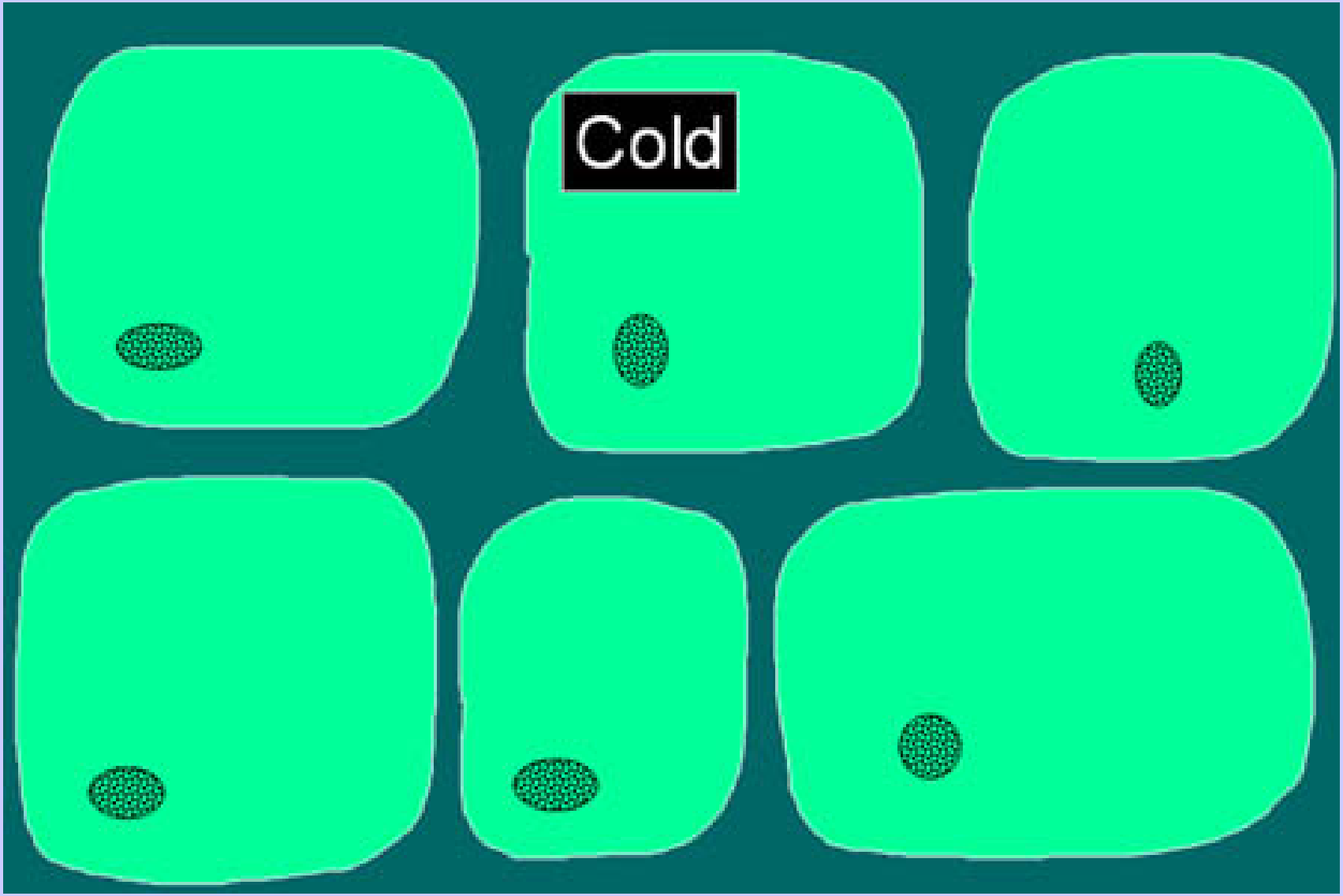
10) Finally, at very low temperature, molecules become locked in place and an amorphous solid is formed. Water that becomes solid without freezing is said to be "vitrified":



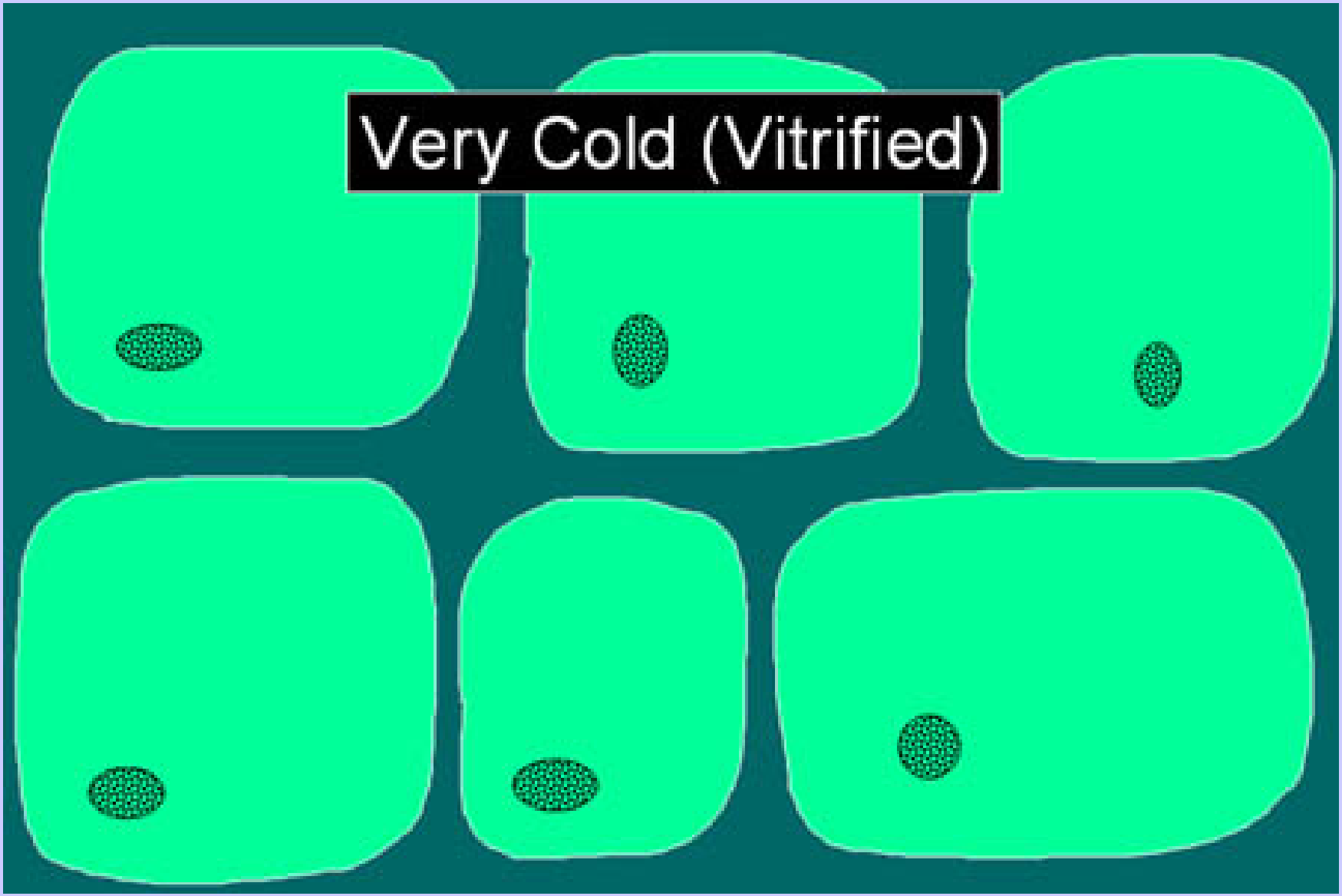
11) Cryoprotectants are added to biological system before deep cooling:



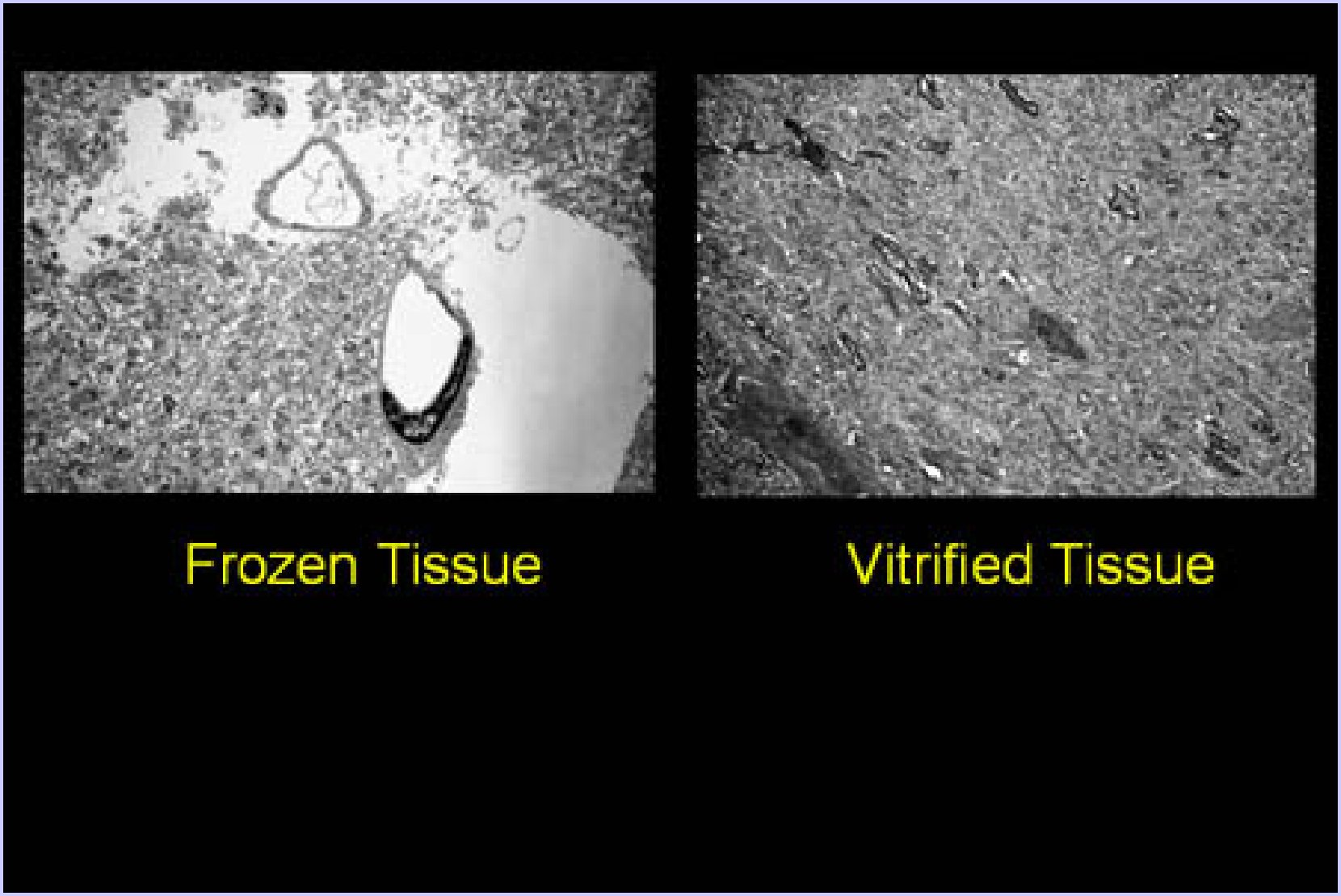
12) There is no damage to cells during cooling because no ice is formed:



13) Finally cells are vitrified and biological time is stopped:

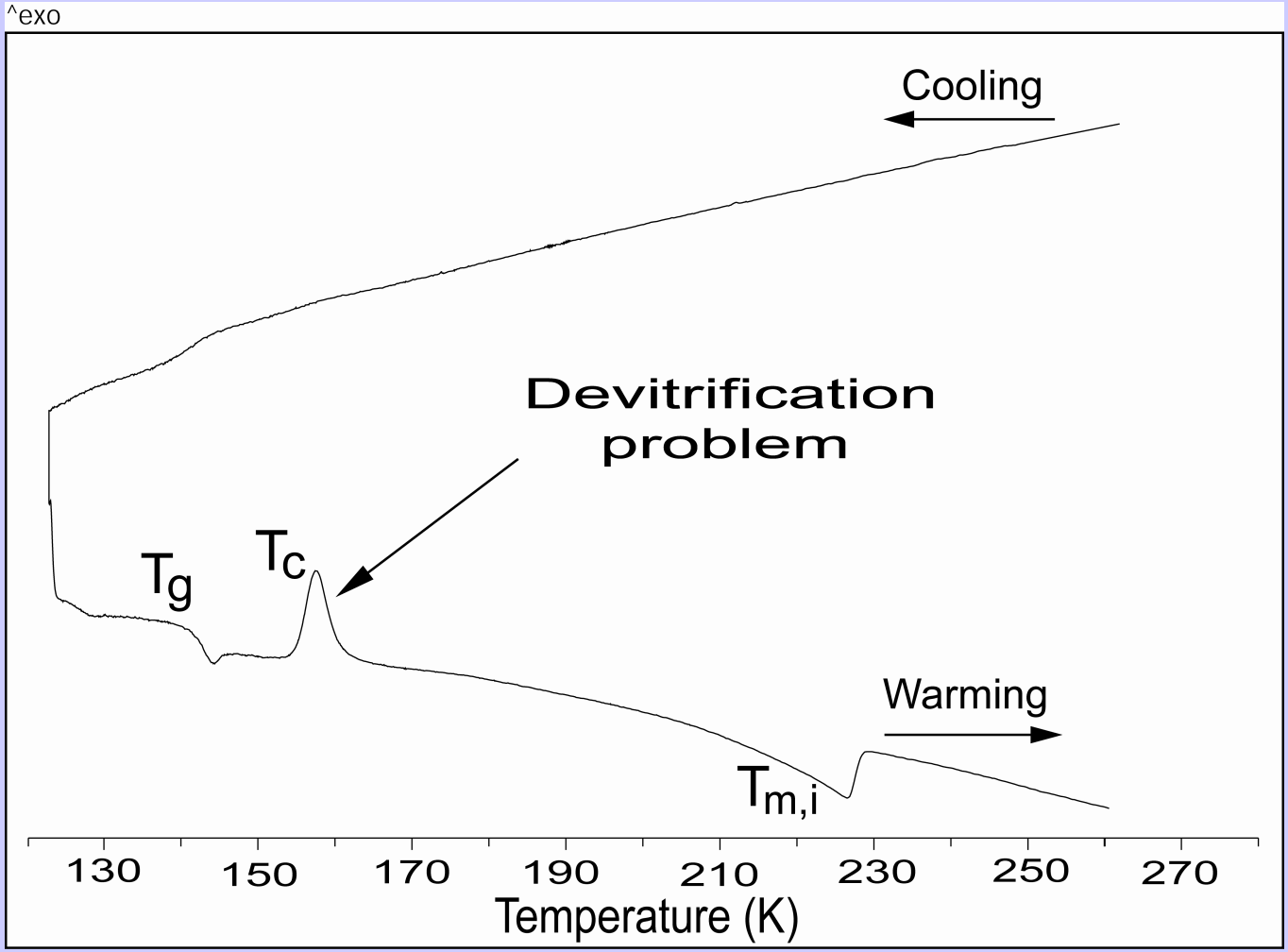


14) Because no ice is formed, vitrification can solidify tissue without structural damage:



15) Entire organs can be solidified and stored at low temperature. Scientists are working on ways to reduce the toxicity of the cryoprotectants used to make water vitrify to allow banking of organs for transplantation. The toxicity that still does occur with vitrification of human organs will be reversible with future molecular repair technology.

It is much easier to avoid ice crystallization when cooling than prevent it when warming i.e., to avoid the devitrification problem. The above frozen kidney cannot be revived if many cells are killed on warming.



How to escape the devitrification problem?

Efficient and nontoxic ice blockers, for example, synthetic anti-freeze proteins, will strongly reduce the mechanical damages produces by the devitrification problem in the living tissue.

CONCLUSIONS

- **Since cryobiology and cryonics are at the interface between physics, chemistry, and biology the knowledge of physical-chemistry lows is very important.**

- **While at present there is much uncertainty about whether cryonics is justifiable, a personal choice is still the governing force in the matter.**