Stable thermal oscillations in columns of partially supercool water

A poster presentation by

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Abstract:

Supercooling the water at the bottom of a column of water can effectively increase the rate of heat flow through it from the top to the bottom. Furthermore, vertically stable as well as vertically mobile "thermal oscillations cells" may spontaneously arise. The mobile oscillations move up the column and the stable oscillations remain vertically fixed for long periods of time. Temperature fluctuation may exceed 2^{o}C.

Background and experimental results:

In 1968 George Veronis wrote, "A stabilizing gradient of solute inhibits the onset of convection in a fluid which is subjected to an adverse temperature gradient. Furthermore, the onset of instability may occur as an oscillatory motion because of the stabilizing effect of the solute." (1) In all previous theoretical and experimental studies of the phenomenon described by Veronis, **heat** was supplied from below. Here we **cool** from below and used either heavy water (D_2O) and or sugar as the solute. We show several examples of stable thermal oscillations produced in partially supercooled columns of water configured as shown in fig. 1. The water must be partially supercooled and may or may not have a solute added. If during a run latent heat is released, oscillations abruptly end. The solute may be added before the start of cooling or during cooling. However, the effects are quite different. The oscillations often (but not always) spontaneously appear near the bottom of the column and sometimes move up.

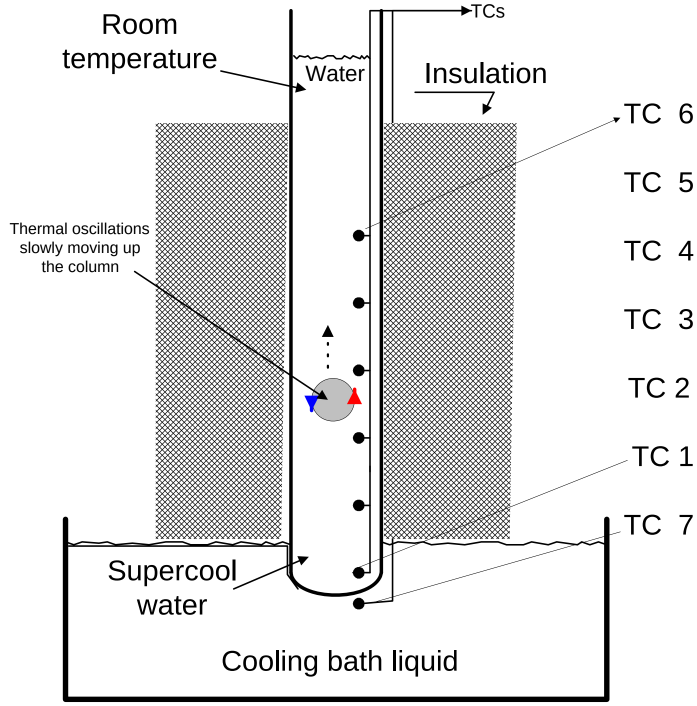

Fig. 1. Schematic illustration of a typical experimental set-up. The cooling bath is a Lauda/Brinkmann RM6 Refrigerating Circulating Bath. The thermocouples are Omega Engineering Type K Dia/Ga 40 and are 1 cm apart. The water container is a glass test tube typically 1.4 cm in diameter and ~10 cm in length.

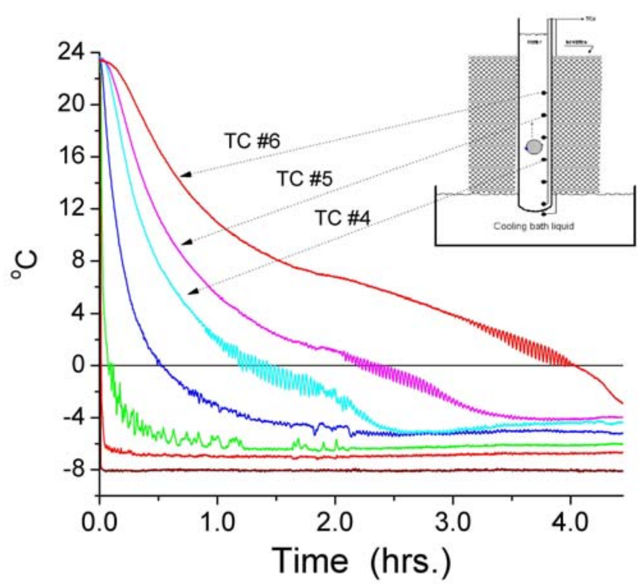

Fig. 2. Sugar (120mg) as sugar water was added to 12 ml DD water just prior to the start of cooling. The solute was added with a dropper at the top of the column. Here we show evidence of a well formed "thermal oscillation cell" moving up the column from below thermocouple 4 (TC 4) and passing TCs 5 and 6.

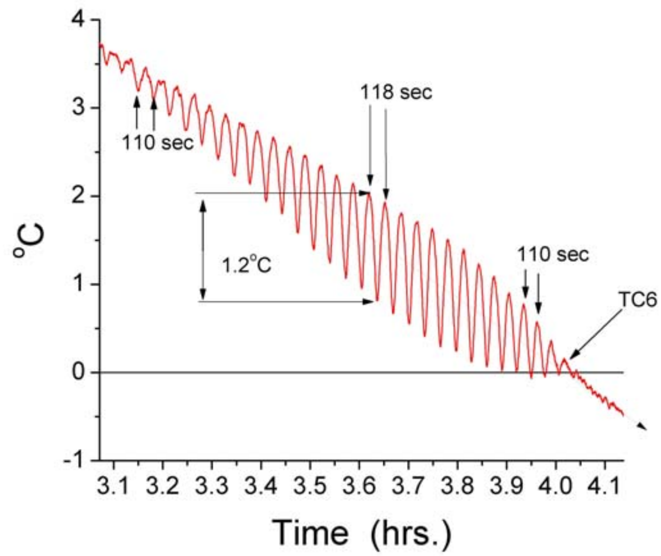

Fig. 3. Here we show the response of TC 6 (from fig. 2) to the approach and passing of a "thermal oscillations cell" on its way up the column of water. The cells vertical velocity up the column was ~1 cm/hr between TC5 and TC6.

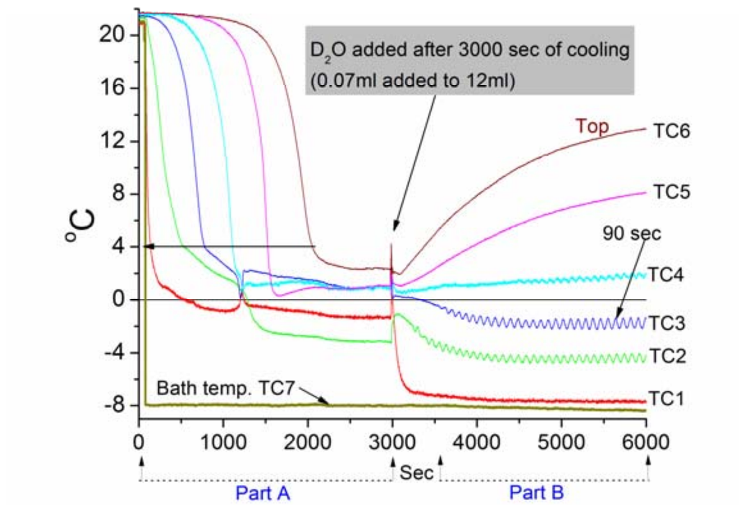

Fig. 4. Cooling curves of "pure" water with the bottom tip of the test tube inserted into the cooling bath as shown in fig. 1. The top TC (#6) cooled to <4°C in about 2000s. Notice that after the addition of D_2O at 3000s at the top of the column, the temperature of TC6 began to rise and the temperature of the bottom TC1 abruptly falls. Convection with heat flow down the column ends following the addition of the solute D_2O. Note in **part A** that the bottom of the test tube is more than 7°C warmer than the bath due to heat flowing down the column. After the addition of D_2O it drops to <1°C above the temperature of the bath. Notice in **part B** that a **"**thermal oscillations cell" spontaneously develops shortly after the addition of D_2O.

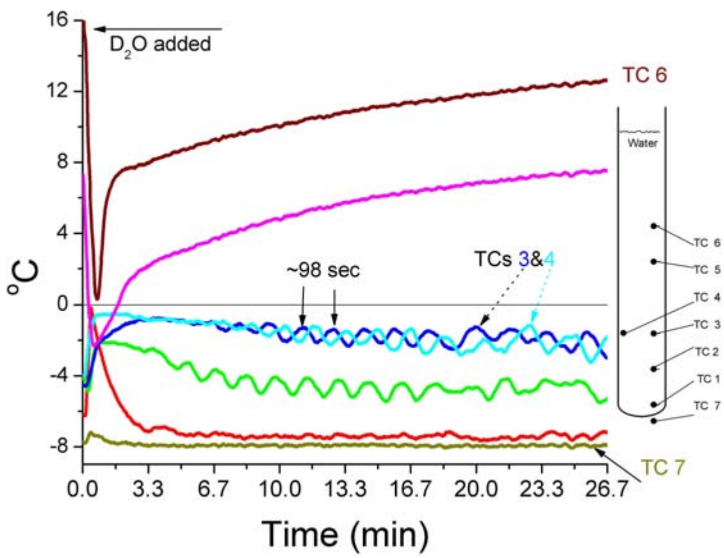

Fig.5

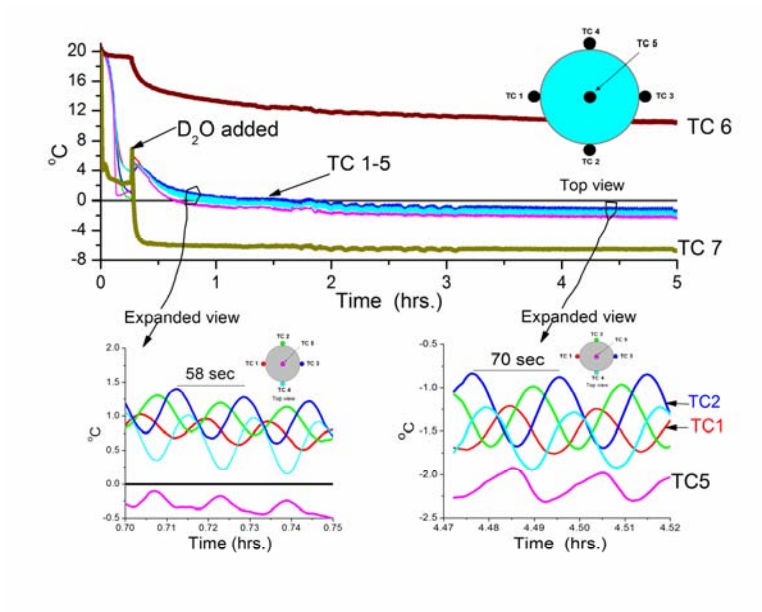

Fig 6

Figs. 5 & 6. Here we investigated the "thermal oscillations cells" by changing the position and geometry of the thermocouples. By geometry, I mean their three dimensional positions inside the test tube. In all previous runs the thermocouples were 1cm apart in a vertical line adjacent to the inside wall of the test tube. The new TC positions are schematically shown in the figures. In fig. 6, TCs 1-5 are in the same horizontal plane 1.5cm above the bottom of the test tube.

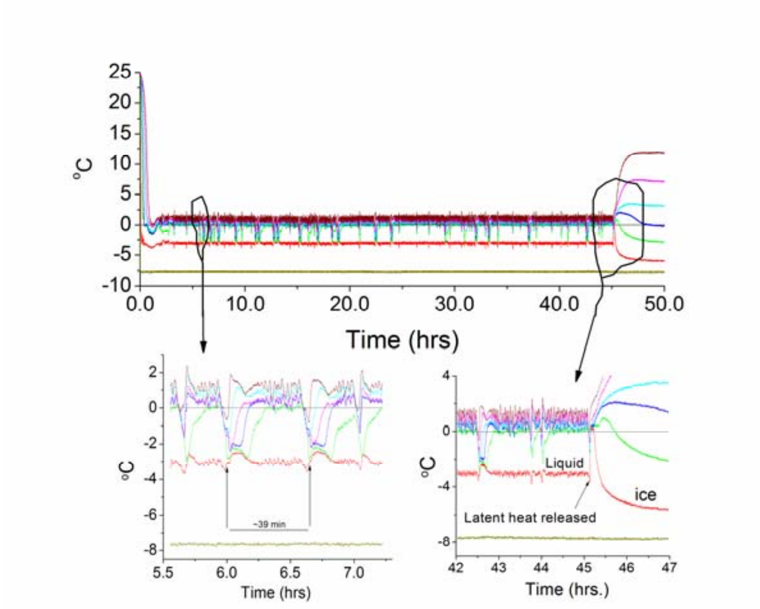

Fig. 7. An example of irregular thermal oscillations lasting more than 45 hours and ending only after latent heat was released. The geometry of the thermocouples was as shown in fig. 1. We never observed oscillations when ice was in the water.

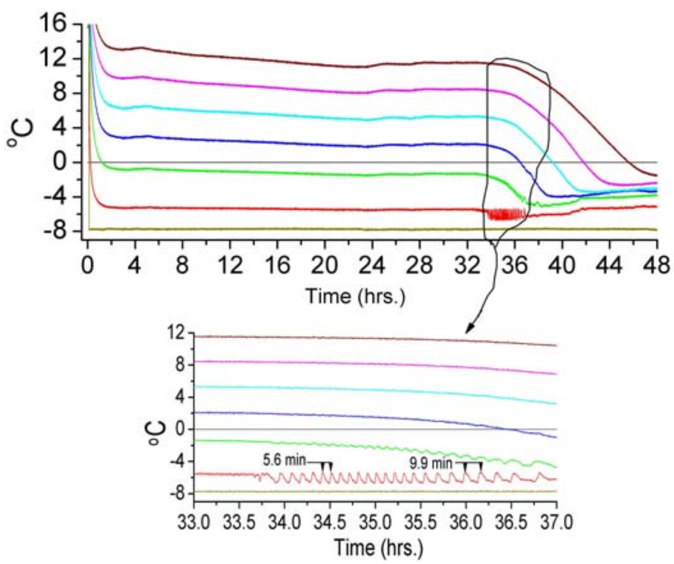

Fig. 8. Here we show evidence that the effect of sugar on convection may vary from run to run. Here cooling to below 0^{o}C did not occur for more than 32 hours. In other runs cooling to below 0^{o}C occurred in less than two hours. It appears that the onset of thermal oscillations in the bottom of the test tube where the water temperature was ~-6^{o}C triggered the cooling process.

Thermal Oscillation cells

Period… 45 sec - 16 min.
Duration… 15 hours (stable)
Temp… Up to 2.2^{o}C
Cell velocity… 0-1cm/hr

During the time of this work a test tube of tap water was held at -15^{o}C for 422 days.

Conclusion:

Supercool water at the bottom of a column of water can effectively reduce the water's resistance to heat flowing through it from top to bottom to nearly zero. With heat flowing down the column "thermal oscillation cells" can be produced and studied in real time over many hours, even days. This may be the first time this phenomenon has been studied in supercool water.

Refs.

(1) Veronis, G., Effect of a stabilizing gradient of solute on thermal convection, J. Fluid. Mech., 315-336 (1968).
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(3) Gorman, W. R. and Brownridge, J. D., Vertical movement of isothermal lines in water, J. of Heat Transfer, 131, 064501-3 (2009)

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