Ice Phase Transition as a Sample of Finite System Phase transition

M.R.Khoshbin-e-Khoshnazar

Physics Department,
Curriculum Development Center Organization & Educational Planning,
P.O.Box 15855-363,Tehran, Iran
E-mail: *khoshbin@talif.sch.ir*

(*Submitted: 11-04-16*)

Abstract

A phase is a physically homogeneous part of a substance separated from other parts of the system by an interface. Claim is that a transition from one phase to another at a given pressure occurs at a strictly constant temperature, and e.g. for the ice, it remains solid until it temperature reaches its melting point at 0°C. At that point, the ice stops getting warmer and begins to melt without a temperature change. Experiments show this claim is not correct and should be modified. The discussion concerning phase transitions in finite systems is certainly an interesting subject. Thermodynamic phase transitions are only defined for infinite systems. It has been shown this feature is common aspect in nuclear matter phase transitions, as well.

Key Words: *Phase transition, Ice Phase transition, finite size, percolation, textbook*

Phase Transition

I have reviewed the discussion on phase changes in several introductory physics textbooks [1-7] and found that all of them either imply or state outright that a body will not undergo a phase change until the entire body reaches the transition temperature. This is of course not the case; otherwise an entire ice cube would melt at once rather than from the outside in! Only Young and Freedman [2] hint at this by stating “If we add heat slowly, to maintain the system very close to thermal equilibrium, the temperature remains at 0^oC until all the ice is melted.” In the discussion of phase transitions, none of the texts explicitly mentions the possibility of a thermal gradient within the body or that the entire body does not typically change phase simultaneously. When I contacted with Jearl Walker (author of *Fundamentals of Physics* and *The Flying Circus of Physics*) about this matter, he wrote me in private letter :"…of course, I agree with you. What I say in class is that if I hold a blowtorch to an ice sheet…,I can get liquid water running down over the remaining subzero ice. However, I do not to get into that much details in the textbook because *we can not do homework problems…*So, I hope that the real details, such as you have done, are brought out in upper level thermodynamic courses…"

Actually, some years ago it has been shown in an abandoned paper [8] -by an experiment- that the ice has no definite melting point and is melting at a temperature below 0°C and gradually melts by increasing temperature: The ice has been placed in the cylindrical plastic glass and then the system puts in the water of a big tank (isothermal source). Since the temperature of the water in the big tank does not change significantly when the ice melts, it chose as an isothermal source. To avoid any error they placed thermometer's probe on the center of block ice surface and recorded the temperature as a function of time. The ice initial temperature was -4.2 °C, and that temperature gradually increased to 0.0 °C over a total time of about 15 minutes. This is exactly what one would expect. At time = 0, the entire block was at a temperature of -4.2 °C. The temperature at the probe increased only very slowly since it was insulated from the environment on all sides . As heat from the surroundings was gradually conducted through the ice to the probe, the temperature readings slowly increased, asymptotically approaching 0.0 °. In °C approximately 1/3 of the initial ice volume has been melted**.** While thermodynamics tell us:" in the typical transformation ice(-4.2°C) to ice(0°C),the ice *does not* change (melt) until to reach 0°C and then melts in an *isothermal* process in 0°C (see fig.1)."While their experiment showed that in 0°C one-third of the initial ice volume has been melted and the phase change occurs *in the earlier time and temperature* (in that experiment, approximately in -3.6°C) in an *non-isothermal* process. Results has been shown in Fig.2. In other words, the suggested typical phase transition(fig.1) is not correct and first part of it should be replaced by Fig.2. As it explained, it relates to heat flowing per time across area of the ice for *temperature gradient* which known as *thermal conductivity*.

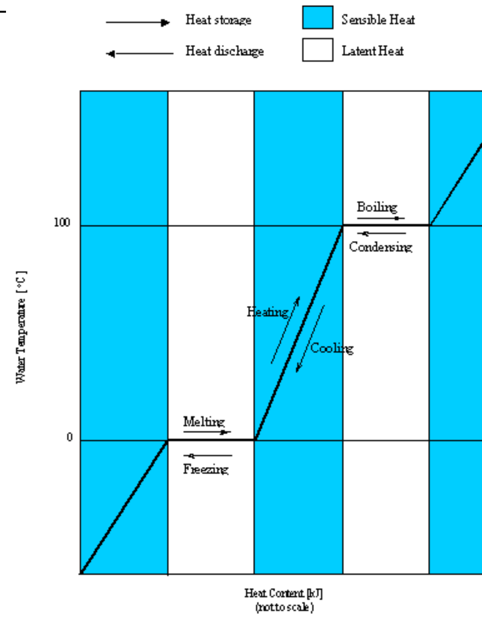

Fig.1 suggested typical phase change for water which introduced in *introductory physics textbooks* . [Adapted from: freespace.virgin.net/m.eckert/new_page6.htm]

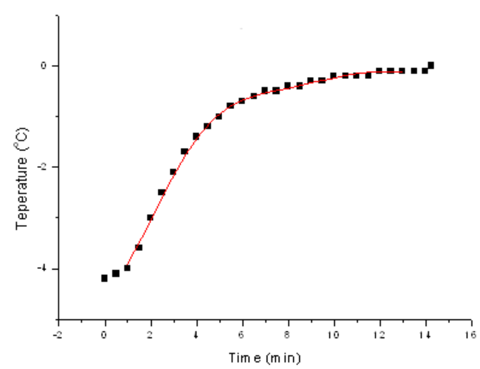

Fig. 2 The temperature vs time data which is fitted by polynomial curve (red curve).

The reason is that the ice at the center would not begin to melt until the temperature there reached 0°C. In other words, this problem can only be solved by treating differential thickness elements and by recognizing that the ice temperature is not uniform during the phase transition though the temperature at the interface where the melting occurs is fixed at 0°C.

Note that we addressed finite-size and finite-time corrections to the infinite-time bulk phase transition idealization of water. The suggested typical phase change figure is correct in the infinite size limit, given an arbitrary long time scale to establish equilibrium. In other words, the thermodynamic phase transitions are only defined for *infinite* system. Of course, just about everything in a introductory textbook is idealized and full of caveats, not all of which are mentioned and in an introductory treatment it is simply not possible to cover all real-world complications in all physical processes, but the discussion concerning phase transitions in finite systems is certainly an important and interesting subject and it should be noted.

Amazingly, I recently informed about some other papers which suggested same feature is common aspect in nuclear matter phase transitions, as well [9-12]. As we noted already, the strict thermodynamic sense phase transitions are only defined for *infinite* systems- theoretically, systems for which the number of elementary constituents is comparable to Avagadro's number. There are similar investigations of finite-size modifications of nuclear matter phase transitions that they do not just constitute small modifications, but that they dominate the observables. The task of theoretical calculations based on finite discrete lattices is to extrapolate to infinite lattice size. In the nature there are a few systems with numbers of constituents on the order of 10^2 to 10^5.One of them is the fragmentation of atomic nuclei. For decades, there have been speculations that we may be able to see a phase coexistence between the Fermi liquid of ground state nuclei and the hadronic gas phase of individual nucleons and / or small cluster. There is similar feature might also for molecular fragmentation (for Buckyball these studies were undertaken). Another phase transition postulated for finite systems is that between a hadron gas (where quarks and gluons are confined in color singlet) and plasma of quarks and gluons where they can move freely across the entire volume. Under laboratory conditions, this phase transition could be able to explored by central collisions of high-energy heavy ions at beem energies above 10 Gev per nucleon. What all of these mesoscopic systems have in common is that their thermodynamic state variables can not be observed directly. All systems are only transiently excited to the energies that are sufficient to explore the phase transition.

It may be percolation theory [13] could be explained this feature. In such systems, the injection of excitation energy results in constituents moving apart from each other beyond the range of the interaction. This bond breaking causes neighbors to loose contact with each other. Consitituents that are still contacted via bonds will end up as clusters in detectors.

Acknowledgment

I would like to thank Wolfgang Bauer at Michigan state of University, for helpful discussion and a number of suggestions and Jearl Walker at Cleveland State of University for our private communication.

References

1.David Halliday, Robert Resnick and Jearl Walker, Fundamentals of Physics, John Wiley & Sons, 10th editon, 2012

.

2.Hugh D.Young and Roger A.Freedman, University Physics, Addison Wesely Publishing co. 14th edition, 2016.

3.Wolfgang Bauer and Gray D.Wsetfall, University Physics,McGraw-Hill, first edition, 2011.

4.John Cutnell and Keneth Johanson, Introduction to Physics, John Wiley & Sons, 9th edition, 2013.

5.Alan Giambatista and Betty Richardson, Physics, McGraw-Hill,second edition, 2008.

3.Vern J.Ostdiek and Doland J.Board, Inquiry into Physics, Thomson, 5th edithon,2005.

4.Paul A.Tipler, Physics for scientists and engineers, W.H.Freeman, 4th edition,1999.

6.Frank J. Blat, Principles of Physics, Allyn and Bacon, 3th edition,1989.

7.Hanc C.Ohanian, Principles of Physics, W.W.Norton, 3th edition,1994.

8. M.R.Khoshbin-e-Khoshnazar,"Second Look on the Ice Phase Transition". Physics Education (India) **25** ,113(2008).

9. W. Bauer and A. Botvina, "Pre-Equilibrium Particle Emission and Critical Exponent Analysis", Phys. Rev. C **52**, R1760 (1995).

10. W. Bauer, "Extraction of Signals of a Phase Transition from Nuclear Multifragmentation", Phys. Rev. C **38**, 1297 (1988).

11. W. Bauer and S. Pratt, "Size Matters: Origin of Binomial Scaling in Nuclear Fragmentation Experiments", Phys. Rev. C **59**, 2695 (1999).

12. W. Bauer, "Common Aspects of Phase Transitions of Molecules, Nuclei, and Hadronic Matter", Nucl. Phys. A **681**, 441 (2001).

13. Dietrich Stauffer and Ammon Aharony, *Introduction to Percolation Theory*, Taylor & Francis, second edition, 1994.