Preventing Phase Transitions: the transition to the epidemic phase

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1. *Phase transitions of general interest*

Phase transitions are keenly studied, in great quantitative detail, by physicists of all hues. I shall, in this article, discuss phase transitions as of general interest without the mathematical rigour of a physicist. My eventual emphasis is on situations where we want to prevent an expected phase transition.

The term 'phase transition' is very often used colloquially. The criterion in such usage is that a phase transition occurs when incremental changes stop having incremental effects, and cause a sudden qualitative change in properties. One such colloquial usage is by the neuroscientist Ramachandran, in his book "**The Tell-Tale Brain"** [1], where he starts by describing the gradual warming up of a block of ice close to the melting point. He describes that after incremental changes in temperature "all you have that you didn't have a minute ago is a slightly warmer block of ice" until a critical temperature when it transforms into water with striking and qualitative changes in physical properties. Change from ice to water (and from water to ice), or from water to steam, are examples of incremental changes that were causing incremental effect and suddenly cause a striking effect, and he uses this as a definition of a phase transition. Ramachandran[1] then suggests that incremental changes in the size of the brains of our ancestors over millions of years followed gene-based Darwinian evolution, but then culminated in a 'mental phase transition' about 150,000 years ago. According to him, the incremental increase in the size of the brain resulted in succeeding generations of apes having slightly better motor and mental abilities, and the hominin brain reached nearly its present size about 300,000 years ago. He argues that this mental phase transition was associated with the development of, among various other capabilities, our ability to wonder. The Cognitive Revolution, when homo sapiens evolved imagination, can be attributed to this phase transition. As we wonder at our ability to wonder, we are glad that this mental phase transition took place!

As mentioned above, change from water to ice is a phase transition. So is any liquid changing to a solid. And we have a phase transition when molecules in a solution form a crystal, as when a solution of salt or of sugar dries out and we get crystals. In the book "**Gene Machine**" [2], Ramakrishnan describes the importance of using X-ray diffraction from crystals of complex molecules to determine where the atoms in a molecule are. In his attempt to determine the structure and function of the ribosome, that contains hundreds of thousands of atoms, he describes the immense effort, sustained over many years, in growing good crystals. He describes his attempts in initial years of growing good crystals of even proteins. He states that when "you let proteins dry out, though, they just form amorphous goop, not crystals". He describes the slow and tedious process necessary to ensure that "the proteins will come out of solution by packing regularly against each other to form crystals". Ribosome contains over a million atoms, including a large number of proteins. The molecule is large and floppy and during crystallization, even if it finds its way to the correct position in the growing crystal lattice, it may not sit in exactly the correct orientation as its neighbouring molecules [2]. A major part of Ramakrishnan's book describes his work, leading to the Nobel Prize, ensuring completion of the phase transition resulting in single crystals.

But there are phase transitions that we try to prevent.

2. *Preventing a Phase transition*

Physicists classify the liquid to crystal phase transition as a "first order" phase transition that proceeds at a fixed temperature T_C with the removal of "latent heat". These phase transitions can be 'postponed' to occur at a temperature lower than T_C during cooling, through the formation of a supercooled liquid [3], but there is a limit to which it can be postponed. (What happens at this limit temperature, as the supercooled liquid finally undergoes the phase transition it was trying to avoid, is a matter of great current interest [3].) But the forming of 'amorphous goop', or glass, prevents the phase transition altogether.

While Ramakrishnan was trying hard to *not avoid* the phase transition, there are cases where civilization has advanced and mankind has benefitted by *preventing* phase transitions. Glasses have existed for close to four thousand years, and technology developments during the last century have enhanced the availability and utilization of strong and large-sized transparent glasses. Transparent plastics also result by preventing the liquid-to-solid transition. These transparent amorphous materials, formed by preventing a phase transition, have greatly influenced our civilization by allowing us to see regions exposed to the ambient while sitting in controlled atmosphere. The visuals of our corona-warriors using transparent 'amorphous goop' are all-pervading. The technology of manufacturing has advanced greatly, while we are still seeking a satisfactory conceptual model to understand (and predict) how the transition to the crystal is prevented in the supercooled liquids [4,5].

A structural glass is formed by preventing the liquid to crystal transition. The underlying concept has been generalised in recent years; preventing a magnetic first-order transition results in a magnetic glass. In both cases, the kinetics of the phase transition is arrested. While in structural glasses it is the kinetics required for diffusion to adjust to the density of the crystalline phase, in the case of magnetic glasses it is speculated to be the kinetics required to remove the latent heat. Physicists believe that these phase transitions, classified as first order, are prevented by proceeding at a rate faster than some critical rate. Specifically, structural phase transitions are prevented by cooling faster than a critical cooling rate. Is this similar to letting infections spread fast? And hoping for herd immunity?

3. *Public health issues*

Are there other phase transitions that can be prevented, or *should be prevented*?

While addressing vaccine compliance problems Chen and Fu [6] recently studied how the perceived cost of vaccination, and the effectiveness of vaccination, influence the level of vaccination in a population. Vaccination levels were found to rise sharply as perceived cost was brought (through subsidies) below a critical value, and as perceived effectiveness of the vaccine rose above a critical value. They found hysteresis akin to that in magnetic systems as the vaccine cost went back up (or perceived effectiveness went down), so that vaccination levels in the population stayed high for a larger range of these parameters. There was no discussion on whether the return transition to low vaccination levels (on increasing cost or reduced effectiveness) could be arrested, and thus totally prevented. While there is no discussion of the kinetics underlying this transition, there could be a hint in their statement "Hysteresis behaviour of population vaccination equilibrium is more likely to arise in spatial populations than in well-mixed populations" [6].

In an older study, statistical physicists have looked at "Quarantine generated phase transition in epidemic spreading", investigating the role of quarantine levels (without vaccination intervention) and infection probability in making a transition, from the disease-free phase to the epidemic phase [7]. This model showed that knowing the state of neighbours before any physical contact is more effective at stopping the epidemic from spreading. This implies no contact in any pre-symptomatic but infectious phase. There was, however, no discussion on whether the phase transition they found showed hysteresis. The question thus remains whether the transition from "disease-free phase" to "epidemic phase" with raising of infection probability can, as in structural or magnetic glasses, be *prevented*. The transition to the epidemic phase appears to be modelled as a percolation transition that would be continuous or second order and, therefore, may not be '*avoided*'. Healthy clusters coexist, however, with clusters having a plurality of infected individuals, prior to percolation. The nucleation and growth of such clusters (both before and after percolation) is sometimes a first order transition that can be arrested or '*avoided*' [8]. This definitely requires further study.

As a general comment, we note that different infected people have different infection probability, depending on the number of pathogens excreted during the time they are infectious; super-spreaders expose their contacts to much higher viral loads in a given duration of exposure. The viral loads of asymptomatic silent spreaders should, naively, be lower. The opening of a lockdown mainly raises infection probability due to the possibility of asymptomatic silent-spreaders now being put in close contact with non-infected individuals for periods longer than a critical duration. This becomes important when such extended exposure is a one-time event, with one-time contacts. This would be specially relevant for all air passengers. News reports state that at least two of the passengers who took flights on May 25 tested positive. The reports indicate test were carried out on over one hundred passengers. We note the report on May25 that India is currently testing over one lakh per day. The capability now exists for widespread tests in situations where, as the lockdown slowly opens, asymptomatic individuals are in casual but close contact for periods longer than a critical duration.

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