FROM THE EDITOR

The Law of Sigmoidal Growth

The title of this column may (mistakenly) lead to the impression that we are talking about some new law in mathematics or even in economics. Nothing could be farther from this; my musings below mostly stem from my recent encounters with several (interrelated) predictions that the futurist Ray Kurzweil has made. For example, he argues that technological change is exponential, contrary to the common-sense "intuitive linear view." This is his "Law of Accelerating Returns," as expounded in his 1999 book, *The Age of Spiritual Machines*. Kurzweil points out that computer chip speed in microelectronics and economic returns, such as cost-effectiveness, are examples that increase exponentially (rather than linearly) with time.

Kurzweil perhaps is best known for his prediction of The Singularity, at which point he reckons that machine intelligence will surpass human intelligence. On the other hand, I want to discuss below a general trend in the initiation, growth, and subsequent maturation of a research topic that adheres to what I will now call the Law of Sigmoidal Growth. We shall see that while the (intermediate) growth phase itself shares some traits with the exponential trend that Kurzweil talks about, there are other interesting aspects of both the "seeding" and subsequent phase(s) that deserve scrutiny and discussion. It is worth stating at the outset that the trends presented below share features with many natural processes including complex system learning curves [see for example, Gibbs, *IEEE Trans. Neural Networks*, **11**, 1458 (2000)].

I am now going to make a metaphorical connection between the initiation, growth, and maturation of a research topic and nucleation and growth phenomenon as we know it from solid-state chemistry and/or electrodeposition perspectives. In the first instance, research activity is seeded by a landmark paper or a group of landmark papers. One can argue that discoveries deserving of the Nobel Prize fall in this category. In the materials case, a few (foreign) nuclei form on preferred "active" sites (about which we incidentally know very little) in a parent phase during the so-called nucleation period. The parent phase is an electrode surface in the electrodeposition example. In either case, an induction period then ensues during which time "very little" happens at least from a visualization or measurement perspective. Rather abruptly then, the growth phase sets in, during which there is frenetic activity. What is the rationale for these trends in the research case? The landmark research may have appeared in an obscure journal. This gives rise to a time lag (which can vary appreciably) before the research community appreciates the significance of the findings. From a researcher's perspective, the growth phase clearly is the most exciting period to be engaged in. (I submit that the Kurzweil discussion above is most relevant here.) On the other hand, the skeptics among us may call this the "bandwagon phase"! In the nucleation/growth case, new phase growth imparts drastically altered characteristics to the parent material.

Ultimately, "All things must pass" (à la George Harrison and the Fab Four), and the frenetic growth phase is inevitably followed by a slowing down of knowledge assimilation and progress. This is the phase where research findings devolve into being "incremental" rather than "transformative." In phase transformations, the growth zones begin to coalesce and overlap and even interfere with one another such that the growth *rate* begins to slow down. The culmination either is a plateau or a subsequent decay as other effects (*e.g.*, mass transfer in the nucleation/growth case) set in. In the lifespan of a research topic, this translates to researchers losing interest and moving on to other topics for study. One can well argue that the technological development phase (the D in R&D) should ideally set in toward the latter stages of the growth phase. However, this aspect deserves more attention than can be given here because of space restrictions.

From a personal career standpoint, I was exceedingly fortunate to be involved in the growth phase of two areas of research activity (photoelectrochemistry and semiconductor electrodeposition) as I elaborate in more detail in a guest commentary elsewhere [*J. Phys. Chem. Lett.* **2**, 1301 (2011)]. This special issue of the magazine (that Guest Editor Nick Wu has so capably assembled) attempts to capture the essence of these important research topics of crucial relevance to solar energy storage and at their current stage of evolution. Stay tuned.

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