HW1

PHYS4240: Solid State Physics

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1 Author Information

1.1 Philip W. Anderson

Philip Warren Anderson was a theoretical physicist who made a number of incredibly important contributions to the field of condensed matter physics, as well as paving the way to the understanding of the Higgs mechanism in high energy physics. Further, he is credited with the term *emergence/emergent phenomena* within the realm of philisophical science. This was most famously captured in an article named "More is Different" written in 1972. He was awarded the Nobel Prize in Physics in 1977 for "fundamental theoretical investigations of the electronic structure of magnetic and disordered systems", which significantly aided the development of components for computers.

Much to my dismay as a particle physicist, I have also learned that he advocated against the construction of the Superconducting Super Collider, which would have been a 40 TeV proton-proton collider in Texas.

1.2 Robert B. Laughlin

Robert Betts Laughlin is a theoretical physicist and a professor at Stanford University. He, along with Horst Störmer and Daniel C. Tsui, was awared the Nobel Prize in 1998 for work on the fractional quantum Hall effect (something which I won't attempt to try and figure out how to explain in my own words). Some of his current work at Stanford includes research into "correlated-electron" phenomenology, which implies that there is some sort of larger and new kind of quantum self-organization in materials. This idea of emergent phenomena was further explored in a book he authored by the name of *A Different Universe.*

1.3 D. Pines

David Pines was a physicist who worked heavily in a number of fields, most notably in condensed matter and nuclear physics in many-body systems. He, along with other notable physicists at the time like David Bohm and John Bardeen, introduced quasiparticles like the plasmon and also paved the way for the development of the BCS theory of superconductivity. He also helped to organize a large number of workshops and summer schools in the US and abroad and was a member and fellow of many different organizations. Some of his more recent research before his death involved, like others in this assignment, the exploration of the idea of emergent phenomena in matter.

1.4 Steven Weinberg

Steven Weinberg was a theoretical physicist who was immensely impactful for his research in elementary particle physics, in which he won the Nobel Prize along with Abdus Salam and Sheldon Glashow for their development of the GWS theory of the weak force. He is often named as one of the most significant theoretical physicists of the 20th century for his significant contributions to quantum field theory. He is the author of the volumes titled *The Quantum Theory of Fields.* Weinberg was also known to be a "public spokesperson for science" due to his various lectures and publications directed towards a more historical or philosophical point of view. He, unlike Anderson, was a proponent for the SCC!

1.5 John J. Hopfield

John Hopfield is a physicist who is most notably known for his research into neural networks and their applications for physics, for which he and Geoffrey Hinton were awarded the Nobel Prize last year (2024). Two of his most credited articles involved "Hopfield networks", a novel type of neural network, for which inspiration came from spin glass systems. He has also done work is a large number of other fields, such as in condensed matter in his earlier life, such as his PhD work in which he described (and coined the term) polaritons, quasiparticles in crystals. He was also considered Anderson's "hidden collaborator" as efforts were made to explain the Kondo effect.

1.6 Nigel Goldenfeld

Nigel Goldenfeld is a professor of physics at the University of California in San Diego. His work spans several fields, largely condensed matter, statistical physics, living systems, and hydrodynamics. His work in condensed matter physics led to developments for high temperature superconductors. He was also instrumental in the understanding of patterns in slowflakes, and consequently, pattern formation in general in nature. His biological interests were fruitful during the COVID-19 pandemic, as his research helped set up and run a COVID saliva testing system which boasted very quick and accurate results.

2 Essay

I was originally going to do this article-by-article, but I found it harder to analyze one specific topic while also including enough of my own input. For instance, it was quite challenging to try and write an analysis on just *More is Different* by Anderson, since he has one set of things he talks about and a path he takes to his one main argument. The only way I could really provide an analysis that was substantially my own was by bringing in outside stuff, which, by choosing to analyze just the one article, wasn't easy. Further, I don't really understand much physics related to solid state compared to particle physics (yet, at least), and this made it even more challenging. Instead, then, I'll just write my own one of the these articles, sort of, and my goal will be just to share my thoughts on the subject.

This entire topic is particularly interesting to me as a high energy physicist, since my main philosophy is inherently reductionist. Of course, even before reading these articles I knew that, in some capacity, diving into higher and higher energies revealed increasingly little about real-world experiences. As an example, I was able to do predictions that (roughly) matched experiment in my high school chemistry class without needing to even know what a quark is, let alone the pandora's box that is QCD. Even though a proton is a bound state of a bunch of quarks and gluons and atomic properties are governed in part by the number of these protons in the atom, these laws/symmetries of QCD played absolutely no role in the predictions made. Of course, these predictions were never perfect (I clearly remember getting something near a 40% error in one instance), but in principle, a perfect experimental procedure would be sure to produce results that agreed well enough with predictions.

Another example of something even more pertinent to everyday life is the simple act of dropping a ball. The ball's mass along with the Earth's mass create a mutual attraction that brings them together. The Earth is enormously heavy, so it hardly moves at all, while the ball accelerates at $\sim 9.8\,\mathrm{m\,s^{-1}}$ towards the ground. I remember running an experiment of dropping a ball a bunch of times from different heights and using the slow-mo feature on my phone's camera to determine how long each trip took, and then determining the actual numerical value of the acceleration the ball experienced. I never needed to know anything but the simple idea that force and acceleration are directly proportional to mass, a fact developed centuries ago. However, as particle physicists we know that mass is granted to the fundamental particles constituting the ball via the Higgs mechanism. And yet, I didn't even know about this phenomena, much less about anything smaller than an atom, at this point in my education.

However, QCD still happens, the Higgs mechanism still happens, all of the things high energy has discovered still happen on their respective scales, it's not like these things *stop* happening once we start zooming out. My understanding of emergence and "more is different" is that these symmetries simply stop being relavant once we zoom out. Specifically, when we do zoom out and examine a large number of particles that are themselves goverened by these symmetries, the system as a hole no longer does – it gains its own unique type of symmetry that is only apparent, and in some cases *inherent* to large systems.

There was one concise example from the reading that I was able to understand best that made this idea clear to me. This was the idea of spontaneous magnetization, something I looked at when studying the Ising Model for my Computational Physics I project. Zooming in to a magnet, and examining the atoms themselves, we note that the laws governing the atom are rotationally invariant; it doesn't matter how the atom is oriented, it'll still work the same way. However, when you look at the magnet as a whole and lower the temperature a bunch, what we find is that the individual atoms choose to magnetize in one particular direction. This creates a magnetic field, and hence, the laws governing the magnet as a whole now clearly no longer exhibit the three-dimensional rotational symmetry like that of its consituents.

Further, this state stays this way. Unlike the ammonia atom, something discussed by Anderson, such a large structure is in no way expected to spontaneously invert itself via quantum mechanial tunneling or any other phenomena in any finite amount of time. This is simply the lowest preferred energy state of the magnet. And again, it's not like the individual atoms themselves stop having a three-dimensional rotational symmetry, it's simply that by examining the magnet as a large collection of atoms, that symmetry has been "broken", and it is no longer obeyed by the composite system. A new type of symmetry is apparent, or, in other words, *emerges.*

3 New Concepts Encountered