Philip Warren Anderson (1923–2020)

Pioneer of condensed-matter physics.

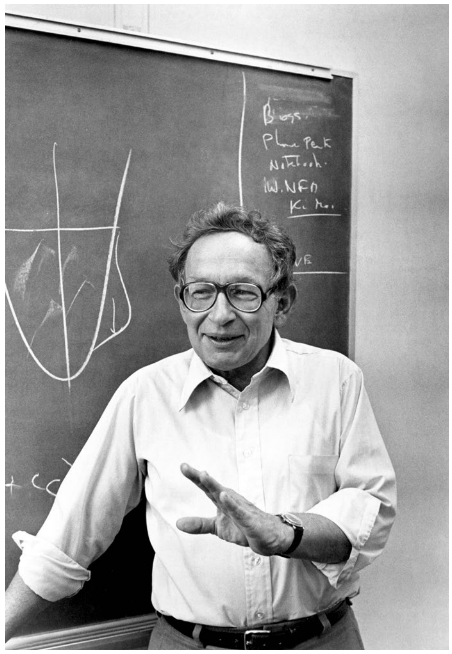
Contrary to the public perception that physics is all about cosmological distances, enormous particle accelerators, and theories of sub-nuclear particles, its largest and most active area of investigation is, in fact, condensed-matter physics. This is the field that, over the course of the second half of the twentieth century, brought us the transistor, the laser and modern communications, and changed the world beyond recognition. Of the many scientists that worked in this area, Philip Warren Anderson, who passed away on 29 March 2020, was perhaps the most influential.

Until the mid-1980s, condensed-matter physics was often synonymous with solid-state physics, a field that came about through the marriage of quantum mechanics with the experimental physics of materials. However, Anderson was an avid proponent of the notion that the study of systems in their 'condensed' phases can be applied to a more general class of problems, including magnetism, superconductivity and superfluidity — all areas to which he contributed significantly.

Born in 1923 to what he described as a "family [of] secure but impecunious Midwestern academics" in Indianapolis, USA, Philip Anderson attended Harvard University, interrupting his studies during the Second World War to design antennas for the Naval Research Laboratory in Washington between 1943 and 1945. He then returned to Harvard to complete a PhD under the supervision of John Hasbrouck van Vleck in 1949.

Anderson then joined Bell Telephone Laboratories in Murray Hill, New Jersey, which was then part of the telecoms giant AT&T. His time there spanned more than three decades, and overlapped with a golden age of industrial research in which fundamental enquiry could co-exist with practical relevance. And it was there that he developed the theoretical work on the electronic properties of metals and semiconductors that would eventually lead to the Nobel prize that he would share with van Vleck and Nevill Mott in 1977.

Specifically, Anderson revealed the deep and subtle effects of disorder on the flow of electrons in a solid, and could account for the manner in which they become trapped by specific atoms through a self-interference effect whereby the electron waves are exponentially damped with distance. This phenomenon has since become known as Anderson localization, and also applies to light and sound waves as well as electrons.



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This was far from Anderson's only contribution during his time at Bell labs, but it is the one that perhaps best highlights both the fundamental and practical relevance of condensed-matter physics — in this case in order to understand the role of impurities on the performance of the silicon chips used to run the rapidly expanding computer industry. It also typified the pragmatic yet highly successful approach to research that made Bell labs the home of countless other discoveries and eight other Nobel prizes: Anderson was proud of his time there, and in an interview in *Physics World* in 2006 recalled how "we had a very high opinion of ourselves, but it was justified. Those were the years when we invented modern technology."

Anderson then moved to Princeton in 1984, where he stayed for the rest of his career. Following the discovery of high-temperature superconductivity in copper oxides in 1986, he was quick to propose the resonant valence bond (RVB) theory as a model to describe it. However, although a number of experimental signatures consistent with RVB have been reported over the years, the model was not found to be universally convincing, although the closely related idea of a quantum spin liquid has certainly lived on within the context of magnetism.

While Anderson's scientific contributions are beyond question — his work on the problem of gauge invariance in superconductivity, which was later cited by Higgs when he uncovered his eponymous mechanism in particle physics is also worth mentioning explicitly — what really distinguishes him is that he was able to transcend his discipline and influence the philosophical underpinnings of science. Most famously, in 1972 he authored an essay in *Science* entitled 'More is Different' (a play on 'More is Better' – a marketing slogan at the time). This would quickly establish itself as a manifesto, not only for condensed-matter physicists, but for the wider tribe of scientists interested in understanding complex systems in many other domains of research.

Anderson took aim at the reductionist hypothesis, widely held among scientists at the time, that all science can be assumed to be controlled by, and therefore derived from, a small set of fundamental laws. Instead, building on the notion of symmetry breaking that had been developed as part of the theory of phase transitions in statistical physics, he put forward a constructivist picture based on the concept of emergence: as a system grows larger, with ever more constituent particles and interactions between them, qualitatively new symmetries, phenomena and yes, even laws of behaviour emerge — laws that cannot be predicted from the fundamental interactions themselves, not even in principle.

The basic idea that nature is organized in a hierarchical fashion and that, somehow, the whole is more than the sum of the parts, was not new in and of itself. For this to be expressed in such essential and compelling terms by a physicist was, and made a lasting impression on an entire generation of scientists. It is no exaggeration to say that they are all Andersonians now. ❐

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Published online: 21 April 2020
https://doi.org/10.1038/s41567-020-0904-y