Obituary

Steven Weinberg

(1933–2021)

Theoretical physicist whose electroweak theory won the Nobel prize.

Steven Weinberg brought the fundamental understanding of nature to new levels of power and completeness. He played a central part in formulating and establishing theoretical physics' two standard models — the standard model of fundamental interactions and the standard model of cosmology. His greatest achievement was to propose the unified theory of electromagnetism and weak interactions, which is still in use. This won him the Nobel Prize in Physics in 1979, shared with his school classmate Sheldon Lee Glashow, and with Abdus Salam.

His 1967 *Physical Review Letters* paper, 'A Model of Leptons', combined disparate ideas about gauge symmetry, symmetry breaking and the classification of particles into an elegant whole. Given the state of knowledge at the time, the breakthrough still calls to mind Einstein's description of Niels Bohr's atomic model: "the highest form of musicality in the sphere of thought".

Amazingly, given its scope and ambition, nothing in the paper needs essential revision today. But it was incomplete in two important ways. First, Weinberg conjectured, but could not prove, that his theory was 'renormalizable', in that incorporating quantum fluctuations would not lead to ill-defined mathematical expressions. That problem was solved for quantum electrodynamics — the theory of photons and their interactions — in the 1950s. It was even harder to crack in Weinberg's unified theory, and its solution brought in new ideas.

Second, it really was just a theory of leptons — electrons, muons and their neutrinos. It left out the world of strongly interacting hadrons, including protons, neutrons and most of the vast zoo of particles observed in high-energy accelerators. Remarkably, however, quantum chromodynamics — the modern theory of strong interactions, based on quarks and gluons — combines harmoniously with Weinberg's model. The same is true for general relativity, Einstein's theory of gravity.

Weinberg had a leading role in orchestrating this powerful consolidation of fundamental physics, in particular by calculating its experimental consequences. The discovery, in the 1980s, of the *W* and *Z* bosons, which had precisely the masses and other properties predicted by his model, was its crowning success.

The other major strand in Weinberg's work was physical cosmology. When his landmark book *Gravitation and Cosmology* first appeared in 1972, high-energy particle physics and cosmology were regarded as distinct subjects, with different cultures and communities. After Weinberg knocked down the barriers, a new generation prospered in the border zone. A central message of the book was that the Big Bang should be considered as a unique, gigantic experiment in high-energy physics. He made his case by showing how hypotheses about neutrino properties could be tested through cosmological observations. His popular book on the topic, *The First Three Minutes* (1977), found a large audience.

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Weinberg was born in New York City to Jewish immigrant parents. He credited his father with encouraging his interest in science. He graduated in 1950 from the Bronx High School of Science, the city's flagship for educating young scientists. Leon Cooper and Melvin Schwartz were near-contemporaries, as well as Glashow, to name just those who went on to get Nobel prizes in physics. It is hard to resist the implication that it is probably good science policy to welcome immigrants and bring bright children together.

After undergraduate studies at Cornell University in Ithaca, New York, Weinberg spent a year at Nordita (the Nordic Institute for Theoretical Physics) in Copenhagen, working on quantum field theory with Gunnar Källén, whom he often mentioned as a strong influence. He completed his PhD at Princeton University, New Jersey, with Sam Treiman advising on his thesis about how the strong interaction complicates the interpretation of weak-interaction observations. He went on to positions at Columbia University, New York; the University of Berkeley, California; the Massachusetts Institute of Technology in Cambridge; and, in 1973, to Harvard University in Cambridge, where he was Higgins Professor of Physics. In 1982, he moved to the University of Texas at Austin, where he remained, teaching until earlier this year.

Scientists, no less than composers, have styles. Einstein and Richard Feynman were rebellious, most comfortable when they were 'thinking different'. Weinberg was not like that. His approach was scholarly. Most obviously, he was keenly interested in the history of physics in the West, about which he wrote several deeply researched and unashamedly 'Whiggish' books, most recently *To Explain the World* (2015).

He paid close attention to other people's work. I remember several rather terrifying phone calls during which he quizzed me about details of mathematical derivations in my or others' papers.

He would not let go of obscurities that caught his attention. Several of his most important investigations were sparked when he perceived gaps or unexplored consequences. His work on electroweak interactions grew out of wrestling with the confused literature of its component ideas. If Einstein and Feynman call to mind Beethoven, Weinberg calls to mind Bach.

Later in his career, Weinberg extended the ideas he had pioneered in new directions. He made suggestions about unified field theory, the nature of dark matter and the possibility of a multiverse. These ideas, attractive but as yet unproven, continue to inspire research.

Weinberg sometimes expressed strong views against religion, such as this: "Anything that we scientists can do to weaken the hold of religion should be done and may in the end be our greatest contribution to civilization." His, more usual, jovial appreciation of the human comedy was exemplified by the way that, given the chance, he would sneak off from stiff parties to play games with the children.

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