RETROSPECTIVE

# Freeman Dyson (1923–2020)

## Brilliant polymath who reshaped quantum physics

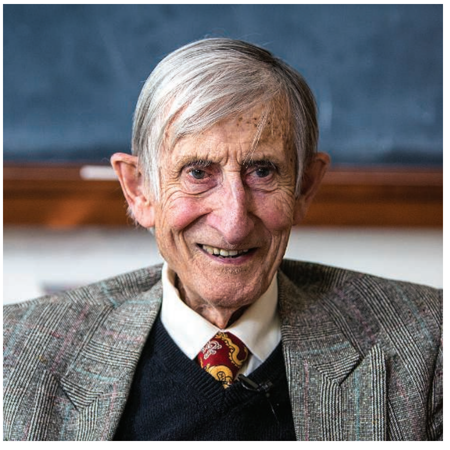
By **Frank Wilczek**

Freeman Dyson, a towering figure in physics and mathematics, died on 28 February at the age of 96. During his long and vibrant life, Dyson explored both concrete and visionary technologies, ranging from safe, small nuclear reactors to proposals to genetically modify trees so they could grow on comets. He documented his adventures in beautifully written books and a marvelous collection of Web of Science video interviews. Dyson's most impactful contribution to physics was his fundamental work on quantum electrodynamics (QED), the theory of how matter interacts with the electromagnetic field. His synthesis of ideas completed the physical foundation for chemistry, materials science, laser physics, and electrical engineering.

Dyson was born on 15 December 1923 and raised in the village of Crowthorne in the United Kingdom. As a young child, he loved to calculate and build, and he retained that joyful curiosity and creativity throughout his adulthood. In 1945, after lending his skills to the Royal Air Force as a civilian during World War II, he earned his bachelor's degree in mathematics from Trinity College at the University of Cambridge. He began graduate studies at Cornell University in Ithaca, New York, in 1947, where he worked with physicists Hans Bethe and Richard Feynman. Although he had not completed his doctorate, Cornell offered him a position as professor in 1951. The following year, he was given an appointment at the Institute for Advanced Study (IAS) in Princeton, New Jersey, where he remained until his retirement in 1994.

Quantum electrodynamics was a vibrant yet extremely murky subject when Dyson began studying it in 1948. Candidate equations had been proposed by Paul Dirac in the early 1930s, but attempts to solve the full equations had led to severe mathematical difficulties. Physicists retreated to a truncated version of the theory, which supported many successful applications. In the years after World War II, however, advances in electronics and microwave engineering enabled more delicate measurements, which went beyond the scope of the abbreviated theory. The challenge of working with the full theory rose to the top of the agenda of theoretical physics. Julian Schwinger and Sin-Itiro Tomonaga showed how to get more accurate equations in a systematic but laborious way, using algebra. Richard Feynman's radically different approach was based on intuition and diagrams. Each approach had advantages and drawbacks, and it was far from obvious whether the differing methods would always yield the same answers.

Dyson unified these varied approaches into a single theory. He showed how to derive Feynman's rules from Dirac's theory mathematically, without guesswork. Thanks to Dyson's work, QED became a theory of unparalleled precision. In several current applications, the successful comparison of intricate theory and refined experiment reaches the level of a few parts per billion. QED is, in Feynman's words, "the jewel of physics."



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The theoretical tools that Dyson fashioned to solve QED have been extremely versatile. In condensed matter physics, they catalyzed Philip Warren Anderson's work on localization and Kenneth Geddes Wilson's work on phase transitions. More directly, they empowered physicists to derive consequences of quantum field theories proposed to describe other fundamental interactions. Today, our best understanding of strong and weak interactions uses theories that are structurally similar to QED but more complex. Without Dyson's work, these theories would have been unthinkable.

In collaboration with mathematician Andrew Lenard, Dyson proved that quantum mechanics explains the stability of matter. This is by no means obvious, because electrical attractions might foster a collapse. Indeed, Dyson and Lenard showed that stability depends on the Pauli exclusion principle for electrons, a property that has no classical analog. Another notable contribution was a series of papers on the statistical properties of energy levels in complex quantum systems. Dyson discovered a splendor of emergent mathematical regularities that transcend differences among such systems.

Dyson's last major work was a collaboration with William Press on the iterated prisoner's dilemma. Press had discovered, through numerical work, strategies that allow one player in that classic game theory problem to dictate the results of the other player when the game is played repeatedly. He showed his puzzling conclusions to Dyson, who—despite being almost 90 years old and a complete outsider to the field—Press thought might help. The next morning, Dyson presented him with the mathematical analysis that cracked the problem. Together, Dyson and Press injected a revolutionary, mathematically brilliant new idea into the problem—a kind of "enforceable deterrence"—that had escaped researchers in the field for decades. In this last work, Dyson beautifully illustrated the enduring power of mathematics to surprise, entertain, and enlighten. It was a fitting conclusion to a creative career that had begun 65 years earlier with important papers in number theory.

Dyson was a brilliant conversationalist. Part of this talent came from his penetrating empathy: He would focus an intense gaze on his interlocutor and process every word. Another part came from his quick intelligence: His answers came in complete paragraphs and were usually right on point. In 1998, when I was writing a review of quantum field theory, I asked many prominent physicists to pinpoint the most important insight about the physical world from that subject. Dyson immediately replied with the answer I had been proud to reach only after considerable thought (namely, that all electrons are exactly the same).

Dyson was wonderfully generous to his friends and colleagues. When my wife, Betsy Devine, organized a monthly newsletter for visitors to the IAS, Dyson contributed a monthly astronomy column. He also had a special appreciation of children. When my daughters spent time in my IAS office, which was directly below his, he never failed to stop by. His eyes sparkled and his expression glowed as he talked with them. He once told me that they were my best work. I was pleased to discover, years later, that when an interviewer asked Dyson what he considered his own best work, he said "raising six kids, who have become productive citizens." ■

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