Everything is Particles

The mathematical formulation of quantum theory based on path integration occupies a central place in modern physics. Textbooks in relativistic quantum theory cover it in part because of its analytical convenience for certain problems, but also in view of its elegance and conceptual appeal. Invented by Richard Feynman in his classic 1948 paper, "A space-time approach to quantum mechanics", the technique expresses the dynamics of quantum systems in terms of a surprisingly simple, almost intuitive, principle of least action.

In Feynman's terms, the evolution of any quantum system follows from a sum of probability amplitudes over all possible trajectories, each amplitude being simply $\exp(i/\hbar S)$, where S is the classical action for the trajectory. This suggests, in effect, that a quantum system differs from its classical analogue because it explores all possible trajectories in space-time at once. One cannot, as usual, say more about which trajectory the system actually follows, except in the classical limit, where classical trajectories emerge as stationary trajectories, for which the action S varies slowly, causing the amplitudes for adjacent paths to add coherently, rather than cancelling out.

It's undeniably beautiful. How did Feynman come up with it? The answer is certainly ninety percent Feynman's individual brilliance, but the historical record also suggests some timely guidance from the greater luminaries of twentieth-century physics.

In his original paper, Feynman attributes his initial interest in this line of thinking to a section in Paul Dirac's famous textbook on quantum mechanics. In a recent exploration of the history of the era, however, Tilman Sauer of the Einstein Papers Project points out that Feynman's approach traces at least some of its motivation back to his earlier efforts with John Wheeler to build a theory of electrodynamics that would abandon the concept of fields, and posit a universe of only particles — an idea that both also discussed in some depth with Albert Einstein, among others.

Wheeler's and Feynman's efforts were motivated by a belief that the conceptual difficulties of quantum electrodynamics might reflect problems present in classical electrodynamics, and have little to do with quantum mechanics *per se*. In particular, while it was clear in classical theory that an accelerated particle must radiate energy, giving it to the electromagnetic field, no theory had ever managed more than an *ad hoc* description of the reactive force on the particle created as a result.

Seeking a better route to quantum electrodynamics, Wheeler and Feynman hoped to resolve this issue of classical field theory in one bold stroke, by postulating that accelerated particles don't radiate, and that there are no fields. They also supposed that particles interact only with other particles, and never with themselves. The resulting theory based on action-at-a-distance puts all the physics into particles and their direct interactions through advanced or retarded influences. The radiation reaction, in their view, reflects not a particle giving energy to a field (and effectively acting on itself through that intermediary), but an interaction between the charge and all other charged matter in the Universe.

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All this enters into the Wheeler–Feynman theory through a principle of least action involving particles, but no fields. And Sauer suggests that they were led to their mathematical formalism, at least in part, by conversations with Einstein. They apparently met for a long discussion at Einstein's home in Princeton, during which he alerted them to earlier work by Hans Tetrode and Walter Ritz, who had also developed similar formulations of electrodynamics involving particles only. Science goes round and round, though it never quite returns to the same place.

These ideas, as Sauer argues, left clear traces in Feynman's space–time formulation of quantum theory, also based on a least-action principle. Indeed, Feynman stated in the abstract that part of his intention was to explore applications that would "eliminate the coordinates of the field oscillators from the equations of quantum electrodynamics".

Eventually, Feynman abandoned that idea, convinced by the Lamb shift in hydrogen that electrons do interact with themselves, presumably through the intermediary of the electromagnetic field.

Wheeler apparently gave up on the idea only later. "Until the early 1950s," he later recalled, "I was in the grip of the idea that Everything is Particles."

Yet the ideas of science do go round and round, and the notion that Everything is Particles hasn't died. To take one example, researchers exploring alternative interpretations of quantum theory — especially those based on the ideas of David Bohm — argue that theories of this type, which have been elaborated for essentially any quantum field theory, are in fact simplest when based on a purely particle ontology; that is, when they assert that only particles, and not fields, really exist.

Proponents of this view also argue, with some reason, that while physicists talk a lot about fields and field theories, nothing in physics, strictly speaking, ever reflects the measurement of a field. Experiments measure particles passing through detectors, or record spot-like marks on a screen. Fields may be seemingly unavoidable theoretical elements, yet the evidence points only to particles.

Feynman, of course, had a practical approach to physics, and pushed 'philosophical' questions to the side. His interest in avoiding fields was expedient — to get a better theory of quantum electrodynamics, which he did eventually help to do, though not exactly in this way.

As Sauer relates, the audience for Feynman's first seminar as a young graduate student at Princeton, at which he presented his and Wheeler's ideas, included several guests that Eugene Wigner had invited specially — the great mathematician John von Neumann, the eminent physicist Wolfgang Pauli and, though he rarely attended such seminars, Albert Einstein.

Feynman later recalled turning "a yellowish green, or something", before he began talking physics and relaxed.

Einstein, with characteristically penetrating logic, commented after the lecture that the ideas were inconsistent with the principles of general relativity. But that, he said, wasn't necessarily so bad. "After all, general relativity is not so well established as electrodynamics," Feynman recalls Einstein saying, "maybe we can develop a new way of doing the gravitational interaction too."

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