A walk in a quantum world

Fantastic Realities: 49 Mind Journeys and a Trip to Stockholm
by Frank Wilczek
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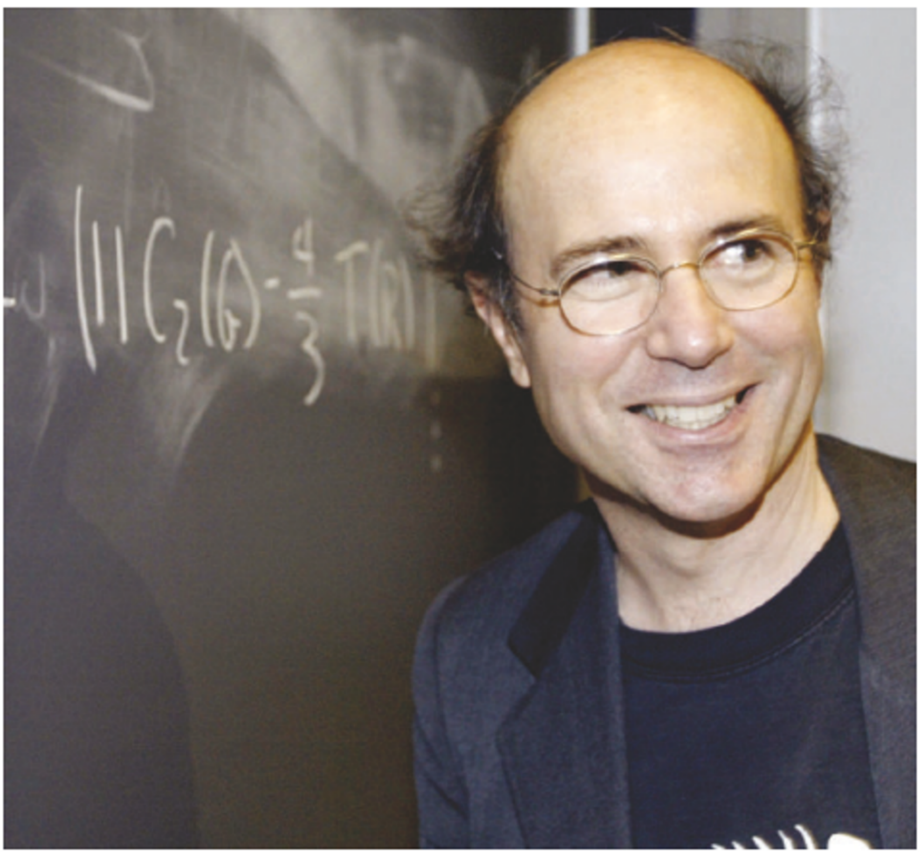
The contemporary picture of the physical world is framed by quantum field theory (QFT), which combines quantum mechanics with Einstein's special theory of relativity. Frank Wilczek's mission to provide a non-technical account of QFT, aimed at physicists who are not specialists in particle theory, lies at the heart of his book *Fantastic Realities*. For non-physicists, however, the book would be hard going.

Wilczek points out that QFT explains three mighty facts about the world. First, that all elementary particles of each type (electrons, say) are indistinguishable from one another. This leads to a refinement of the philosophical concept of 'identicalness'. Second, that particles can behave in two ways when interchanged: the waves describing them can remain the same (bosons) or they can change sign (fermions). QFT can also explain why bosons are particles whose spin is an integral number of Planck units, whereas for fermions the spin is a half-integer (although this 'spin-statistics theorem' could well have a more elementary foundation). The third fact is that for each particle there is a corresponding antiparticle, with opposite value for charge and other quantum numbers.

In this picture, the primary ('fantastic') realities are the quantum fields, and the particles — their elementary excitations — are epiphenomena. Wilczek argues persuasively for this interpretation, different from the view expressed by Richard Feynman, that particles are fundamental, and that QFT is the machinery (including what Wilczek calls "the hocus-pocus of renormalisation") for calculating how they behave. Different particles correspond to different fields. At the heart of the modern theory of matter is the field theory of quantum chromodynamics (QCD), which describes the elementary particles — quarks, with gluons mediating their interactions — that make up atomic nuclei. This is a more elaborate cousin of quantum electrodynamics, which describes electrons interacting by means of photons.

In essence, QCD is relatively simple to describe, but getting physical predictions out of it involves some fearsome calculations and fairly difficult concepts. Wilczek's own contribution to the field was to explain why quarks are never observed in isolation: they appear free at short distances but get tightly bound when separated. This paradoxical behaviour is associated with the concept of 'asymptotic freedom', which won Wilczek his share of the 2004 Nobel prize. The prize ceremony, and the curious culture surrounding it, is described at the end of the book in a blog by Wilczek's wife, Betsy Devine.



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Attractive idea: Frank Wilczek won a Nobel prize for his work on the interactions between particles.

Although the book is largely non-technical, Wilczek's writing is deeply intellectual. The essays are centred around QFT but range far more widely. They display a sensitive appreciation of subtle features of the culture of modern physical science. In particular, Wilczek moves easily between the different levels of theory that describe different phenomena. This is 'reductionism', a term Wilczek hates because it connotes a diminution of our understanding, rather than an augmentation — or, to use Newton's phrase, 'analysis and synthesis'.

Wilczek describes a simpler version of QCD — "QCD lite" — in which the mass of quarks can be neglected. This explains many of the phenomena encompassed by the full QCD; in particular, it accounts for 90% of the mass of protons and neutrons, and therefore of ordinary matter. Thus most of our own mass corresponds to the energy of pure motion according to $m = E/c^2$, which as he points out was the original form of Einstein's iconic equation: "At this level, at least, we are ethereal creatures."

Another of the themes in Wilczek's book is the connections between high-energy theory and condensed-matter physics. These include phase transitions and collective quantum phenomena such as superconductivity and superfluidity ("the world is a multilayered, multicolored, cosmic superconductor"). In three-dimensional space, the only possibilities for identical particles are bosons and fermions. But for physics in two dimensions, there is, as one of the essays describes, a continuous range of intermediate possibilities ('anyons') with important applications in solid-state magnetism. I was disappointed by the absence of an account of Wilczek's astonishing work with Alfred Shapere, applying modern geometrical ideas to the swimming of small creatures and the reorientation of falling bodies such as cats.

Several essays cover essentially the same intellectual territory, but with such difficult concepts the inevitable repetition is no bad thing. In any case, it is fascinating to see Wilczek circling round the same set of ideas. There is much concentrated wisdom here, and he has a deft touch with words.

A delightful address to students contains Einstein's favourite joke and an algorithm for choosing between possible marriage partners. Here Wilczek betrays his incorrigible nature as a theorist, because the algorithm requires advance knowledge of one's likely lifetime number, *N*, of credible suitors. He does not advise the students how to behave when the algorithm fails (as it sometimes will), or when both partners apply the algorithm (probably with different *N*). But for Wilczek himself "it worked out fine". ■

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