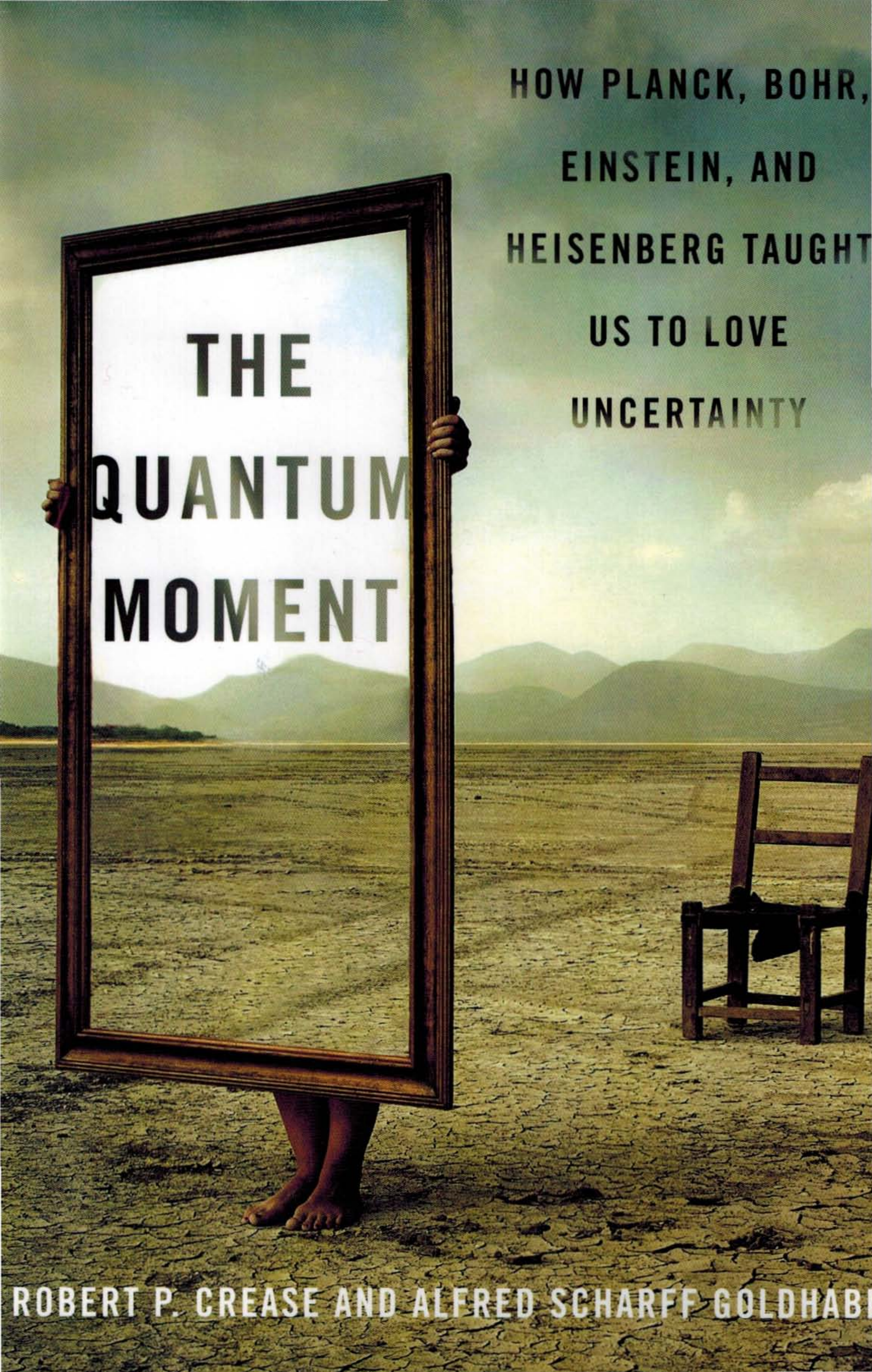
HOW PLANCK, BOHR, EINSTEIN, AND HEISENBERG TAUGHT US TO LOVE UNCERTAINTY
THE QUANTUM MOMENT
ROBERT P. CREASE AND ALFRED SCHARFF GOLDHAB

Chapter Six

Sharks and Tigers: Schizophrenia

Quantum Man is a sculpture by Julian Voss-Andreae installed in the City of Moses Lake, Washington. Vastly different from *Quantum Cloud*, the steel-wool-like sculpture by Antony Gormley discussed in Chapter 4, this one is made of parallel steel sheets 2.5 meters high, and it changes in form as you walk around it. From one perspective it reveals the outline of a human being, while from another the human form disappears entirely. Voss-Andreae calls his sculpture a metaphor for wave-particle duality, or the way in which a quantum phenomenon can appear as either a particle or wave depending on how we look at it.[1]

Quantum Poetics, a book by Harvard English professor Daniel Albright, seeks to understand Modernist poetry—the term *Modernist* reserved for those poets who wrote during the half century or so before the Second World War and who tried to make a clean break with their predecessors—by mapping its authors onto wave and particle models even when their poetry does not mention physics. Ezra Pound was "the Democritus, the Rutherford, the Bohr of poets," a researcher into the elementary particles of poetry, while D. H. Lawrence was a proponent of "feeling-waves, the radiations that interconnect man, woman, snake, cow, moon, sun, through the complicated electromagnetic attraction and repulsion of solar plexus and lumbar ganglion." Yet, Albright continues, both of these poets—and all Modernists—recognized that the behavior of poetry does not fall neatly into either the particle or wave model. He concludes that Modernist poets sought to maintain both con-

Quantum Man by Julian Voss-Andreae.

tradictory models: "the Modernist poets teach themselves how to conceive the poem according to the wave model and the particle model *at the same time*."[2]

Voss-Andreae's sculpture and Albright's Modernist poets are creative because they are two things at once. Both people see this productive schizophrenia as embodying a lesson of quantum physics. But sometimes one simply jokes about quantum schizophrenia. We once saw a cartoon, for instance, picturing the offices of the "Universe Corp R&D Division," in which a bright young engineer, dressed in an immaculate white shirt and tie and holding a coffee cup, approaches God with his latest innovative idea: ". . . and if you could make it a wave AND a particle, that would be great!" God is listening with His usual caring patience, but His thought balloon shows Him thinking, "Christ, what an idiot!"

The Newtonian world was not at all schizophrenic. Everything in it belonged to one of two "bins." In one bin were particles/corpuscles, whose masses were found at specific places, were pushed and pulled by forces, and always had a definite momentum and position. In the other bin were waves, which were described by Maxwellian theories that used continuous functions, obeying differential equations, to depict processes that smoothly evolve in space and time. Both theories involved observable and predictable phenomena. You input information about the initial state, run the program, and out pops a prediction of a future behavior.

Quanta belonged in which bin?

Not clear. During the early to mid-1920s, in the latter days of the first quantum scientific revolution, physicists tended to viewpoint, that is like rotating clockwise from your original viewpoint, and so gives a phase $-a$. Let your friend now rotate you back to right side up. This gives a phase $-b$. We have two phase rotations by $+b$ and $-b$, which cancel each other out. Once we've done that, all that is left is the two counterclockwise rotations by 180 degrees you did on the two particles, giving phase $2a$. However, if we remember that the second time you rotated the particles you were upside down, and therefore rotating the particles clockwise with respect to your original orientation, you find that the net phase was $a - a = 0$ (or equally well, 360 degrees, because a phase rotation by 360 degrees is equivalent to no rotation at all).

Putting all this together, we conclude that rotating twice in the same direction about the bisecting axis must give back the original ψ, which means that exchanging x and y must multiply ψ by a square root of 1, that is, either +1 or −1. The minus case gives the result that for $x = y$, ψ must vanish, which is the Pauli principle, while the plus case gives a wave function that is unchanged by the exchange of the coordinates of two indistinguishable particles, and that's the Bose-Einstein case. So Dirac's statement that these two possibilities are the only ones found in nature is a natural consequence of the rotational symmetry of three-dimensional space.

If we lived in a world with only two space dimensions, then this would not be so, and the angle a could be anything we liked (J. M. Leinaas and J. Myrheim, "On the Theory of Identical Particles," *Nuovo Cimento* B 37 [1977], pp. 1–23). Particles with this possibility available to them have been called "anyons" (Frank Wilczek, "Quantum Mechanics of Fractional-Spin Particles," *Physical Review Letters* 49 [1982], pp. 957–59). For systems built in the laboratory where motion is easy in only two rather than three dimensions, examples have been reported with

Chapter Six: Sharks and Tigers

1. Voss-Andreae should know. He studied physics as an undergraduate in Berlin and Edinburgh, and did graduate research in Vienna with physicist Anton Zeilinger on the double-slit experiments involving the quantum interference of carbon-60 buckyball molecules. According to Voss-Andreae, while the sculpture is not directly related to the mathematics of complementarity, it is related to the mathematics of quantum physics to the extent that, if you assign a chunk of energy—matter for example, or even a person—a frequency according to Planck's equation $E = h\nu$ and then move it, or transform it into a moving frame of reference according to the rules of special relativity, you get plane wave fronts perpendicular to the direction of motion. This is what gave Voss-Andreae the idea of the slabs (personal communication).