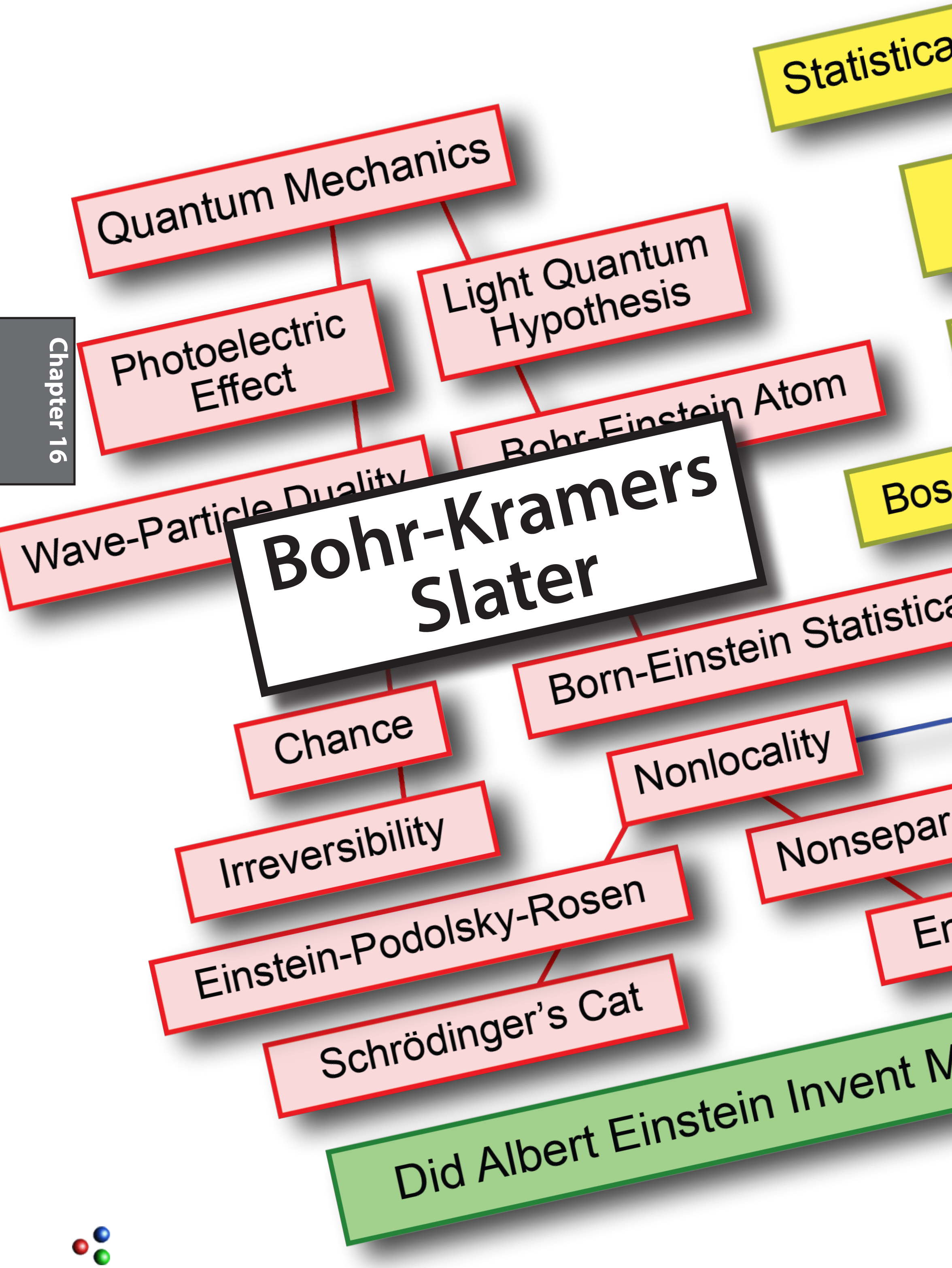
Statistica
Quantum Mechanics
Light Quantum Hypothesis
Photoelectric Effect
Bohr-Einstein Atom
Wave-Particle Duality
Bohr-Kramers Slater
Bos
Born-Einstein Statistica
Chance
Nonlocality
Irreversibility
Nonsepar
Einstein-Podolsky-Rosen
Er
Schrödinger's Cat
Did Albert Einstein Invent M

Chapter 16

Bohr-Kramers-Slater

The 1924 paper of Niels Bohr, Hendrik A. Kramers, and John Clarke Slater was the last major public attempt by members of the Copenhagen school to deny Albert Einstein's light-quantum hypothesis of 1905, although we will show that Bohr's doubts continued for years, if not indefinitely.

The BKS effort was despite the fact that Einstein's most important predictions, the photoelectric effect of 1905 and that a light-quantum has momentum in 1917, had been confirmed experimentally, leading to Einstein's 1920 Nobel Prize. We must however note that the two world-famous experimenters who confirmed Einstein's predictions, Robert A. Millikan and Arthur Holly Compton, both Americans, had not themselves seen the results as validating Einstein's light quanta. Nevertheless, many other physicists by that time had.

Millikan called Einstein's photoelectric idea a "bold, not to say reckless hypothesis" and said although it appears in every case to predict exactly the observed results, Einstein's "theory seems at present wholly untenable."[1]

In 1923, Compton showed that radiation (a high-energy X-ray) was being scattered by electrons, exchanging energy with them, just as if the light rays and electrons acted like colliding billiard balls. Although this was the first solid evidence for Einstein's "light-quantum hypothesis," like Millikan, Compton said his work did not support Einstein's radical hypothesis. Although by 1924 a large fraction of physicists had come to believe light had both wave and particle characteristics, there were still several holdouts. Many were found among Bohr's Copenhagen associates.

It is difficult to imagine what Einstein's feelings may have been after nearly two decades of rejection of what he called his "very revolutionary" contributions to quantum theory.

But surely the negative attitude of Bohr, who with his 1913 model for the atom was the third great thinker in quantum theory after Max Planck and Einstein, was hardest for him to bear.

---

1 Pais, *2005*, p.357.

While the 1924 Bohr-Kramers-Slater theory may have been the most dispiriting for Einstein, it ironically grew out of an original suggestion that was based directly on Einstein's light quantum.

John Slater was a young American physicist who accepted Einstein's radical insights. He came from MIT to Copenhagen with an idea about "virtual oscillators".

But Bohr and Kramers were very explicit about their objection to Einstein's localized quantum of light. They said there is no way individual particles can explain the wave properties of light, especially its interference effects. The very idea that a light quantum has energy $h\nu$, where ν is the frequency of the light, depends on the wave theory to determine the frequency and the associated wavelength, they said.

In his 1922 Nobel Prize lecture, Planck had said,

> In spite of its heuristic value, however, the hypothesis of light-quanta, which is quite irreconcilable with so-called interference phenomena, is not able to throw light [*sic*] on the nature of radiation. I need only recall that these interference phenomena constitute our only means of investigating the properties of radiation and therefore of assigning any closer meaning to the frequency which in Einstein's theory fixes the magnitude of the light-quantum.

And in his popular book on the Bohr Atom in 1923, Kramers had vigorously attacked the idea of a light quantum.

> The theory of quanta may thus be compared with medicine which will cause the disease to vanish but kills the patient. When Einstein, who has made so many essential contributions in the field of the quantum theory, advocated these remarkable representations about the propagation of radiant energy, he was naturally not blind to the great difficulties just indicated. His apprehension of the mysterious light in which the phenomena of interference appear in his theory is shown in the fact that in his considerations he introduces something which he calls a 'ghost' field of radiation to help to account for the observed facts. [2]

2 *Kramers, 1923,* p.175

Einstein's "ghost field" or "guiding field" interpretation for the light wave, whereby the light wave gives the probability of finding a light particle, was thus well known in Copenhagen before Louis De Broglie introduced a "pilot wave" in his 1924 thesis. Einstein may have had this view as early as 1909. See chapters 9 and 14.

What Slater brought to Copenhagen was a variation of Einstein's "ghost field." He suggested that an atom in one of Bohr's "stationary states" is continuously emitting a field that carries no energy but contains a set of frequencies corresponding to the allowed Bohr transition frequencies. Like the Einstein field, the value of the Slater field at each point gives the probability of finding a light quantum at that point. They were slightly different from Einstein's light quanta. Like our information philosophy interpretation of the quantum wave function, Slater's field was *immaterial*.

In any case, Bohr and Kramers rejected any talk of light quanta, but did embrace Slater's concept of what they called a "virtual field." Slater thought it might reconcile the continuous nature of light radiation with the discrete "quantum jumps" of the Bohr Atom. Bohr realized this could only be done if the transfer of energy did not obey the principle of conservation of energy instantaneously, but only statistically, when averaged over the emissions and absorptions of distant atoms.

In just a few weeks the BKS paper was published, written entirely by Bohr and Kramers. It met with immediate criticism from Einstein and others. Einstein objected to the violation of conservation of energy and called for experiments to test for it.

Within a year Walther Bothe and Hans Geiger, who had confirmed the Compton effect, showed that the timing of scattered radiation and an electron recoil were within a tiny fraction of a second, confirming Einstein's demand for instantaneous conservation of energy and proving the BKS theory untenable.

But Slater's notion of a virtual field of oscillators with all the frequencies of possible transitions survived as the basis of Werner Heisenberg's matrix mechanics, to which we now turn.