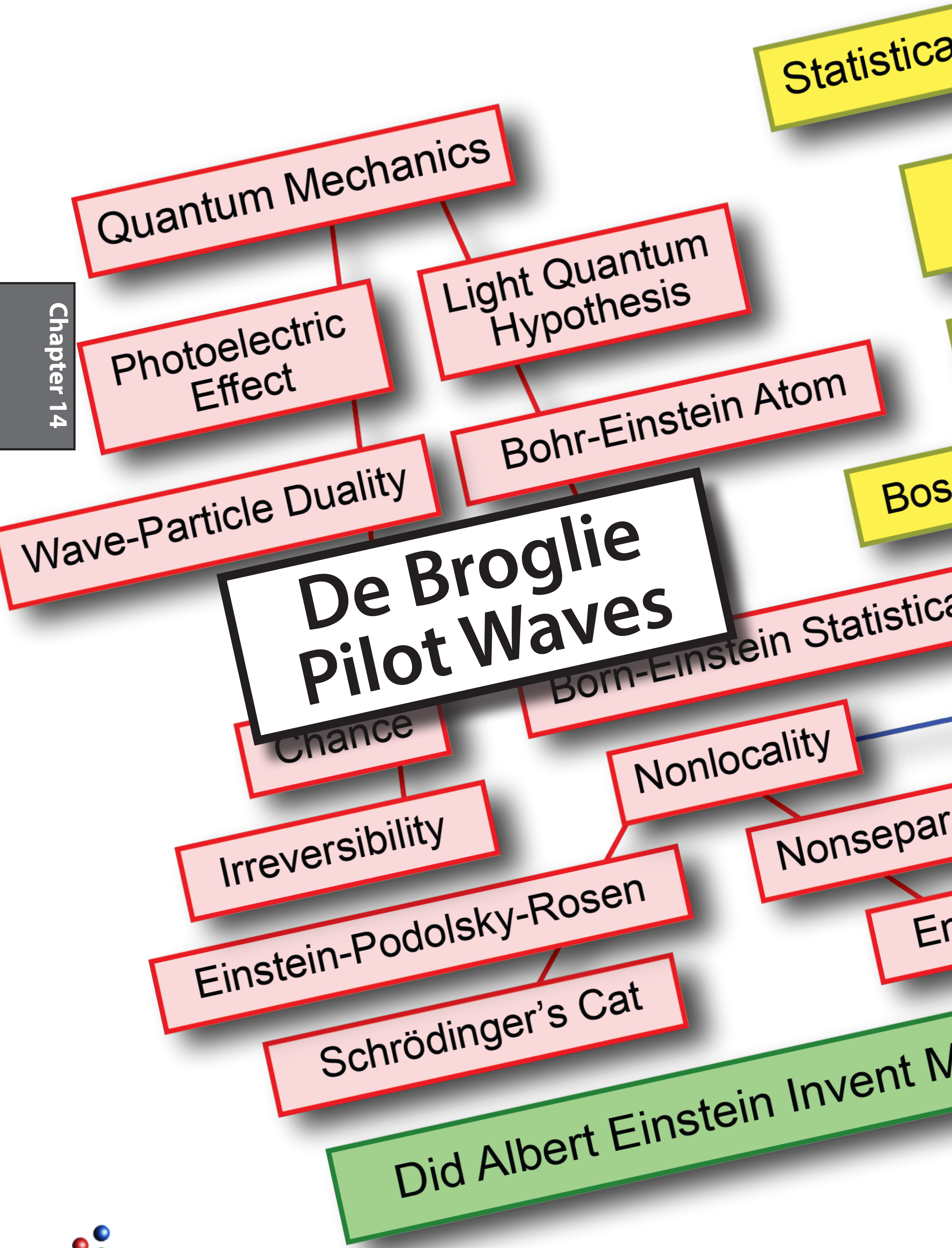
Quantum Mechanics
Light Quantum Hypothesis
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De Broglie Pilot Waves

Louis de Broglie was a critical link from the 1905 work of Albert Einstein to Erwin Schrödinger's 1926 wave mechanics and to Max Born's "statistical interpretation," both considered key parts of the Copenhagen Interpretation of quantum mechanics.

De Broglie is very important to our account of the slow acceptance of Einstein's work in quantum mechanics. He was very likely the first thinker to understand Einstein's case for wave-particle duality in 1909 (as we saw in chapter 9) and to take Einstein's light-quantum hypothesis seriously.

In his 1924 thesis, de Broglie argued that if light, which was thought to consist of waves, is actually discrete particles that Einstein called light quanta (later called photons), then matter, which is thought to consist of discrete particles, might also have a wave nature. He called his matter waves "pilot waves."

> The fundamental idea of [my thesis] was the following: The fact that, following Einstein's introduction of photons in light waves, one knew that light contains particles which are concentrations of energy incorporated into the wave, suggests that all particles, like the electron, must be transported by a wave into which it is incorporated... My essential idea was to extend to all particles the coexistence of waves and particles discovered by Einstein in 1905 in the case of light and photons.[1]

What Einstein had said was that the light wave at some position is a measure of the *probability* of finding a light particle there, that is, the intensity of the light wave is proportional to the number of photons there. It may have been implicit in his 1905 light quantum hypothesis, as de Broglie seems to think, but Einstein had explicitly described a "guiding field" (*Führungsfeld*) or "ghost field" (*Gespensterfeld*) a few years before de Broglie's thesis, in his private conversations.

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1 en.wikipedia.org/wiki/Louis_de_Broglie, retrieved 03/17/2017.

Einstein had used these "field" terms privately to colleagues some time between 1918 and 1921. We don't have public quotes from Einstein until October 1927 at the fifth Solvay conference.

> $|\psi|^2$ expresses the probability that there exists at the point considered a particular particle of the cloud, for example at a given point on the screen.[2]

There are subtle differences between de Broglie, Schrödinger, and Born as to the connection between a particle and a wave. Born's thinking is closest to Einstein with the idea that the wave gives us the probability of finding a particle of matter or radiation.

De Broglie thought the particle is "transported by a wave into which it is incorporated." Schrödinger is the most extreme in identifying the particle with the wave itself, to the point of denying the existence of separate particles. He strongly rejected the idea of discrete particles and the "quantum jumps" associated with them. He vehemently attacked the probabilistic interpretation of Einstein and Born. Schrödinger thought a wave alone could account for all the properties of quantum objects.

Schrödinger brilliantly showed his wave equation produced the same energy levels in the Bohr atom as Werner Heisenberg and Wolfgang Pauli had found with matrix mechanics.

De Broglie used an expression for the wavelength of his "pilot wave" that followed from the expression that Einstein had used for the momentum of a light quantum, the same value that Compton had confirmed a year earlier. Since the wavelength of light is equal to the velocity of light divided by frequency, $\lambda = c/\nu$, and since Einstein found the momentum of a particle with energy $h\nu$ is $h\nu/c$, de Broglie guessed the wavelength for a particle of matter with momentum p should be $\lambda = h/p$.

Note that this is still another case of the "quantum condition" being Planck's quantum of action. Although de Broglie began with *linear* momentum, he now could connect his hypothesis with Bohr's use of quantized *angular* momentum in the Bohr atom orbits. De Broglie showed that the wavelength of his pilot wave fits an integer number of times around each Bohr orbit and the integer is Bohr's principal quantum number.

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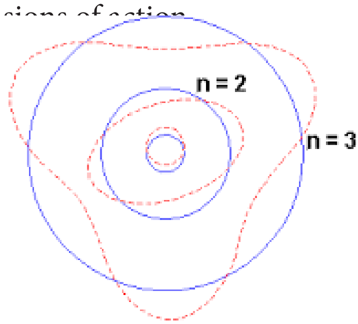
2 Bacciagaluppi and Valentini, 2009. pp. 441.

Once again, what is being quantized here by de Broglie is angular momentum, with the dimensions of action.



Schrödinger was delighted that integer numbers appear naturally in wave mechanics, whereas they seem to be only *ad hoc* assumptions in Heisenberg's matrix mechanics.

De Broglie said in his Nobel lecture of 1929,

> the determination of the stable motions of the electrons in the atom involves whole numbers, and so far the only phenomena in which whole numbers were involved in physics were those of interference and of eigenvibrations. That suggested the idea to me that electrons themselves could not be represented as simple corpuscles either, but that a periodicity had also to be assigned to them too. [3]

De Broglie's hypothesis of matter waves and Einstein's insight into wave-particle duality were confirmed by Clinton Davisson and Lester Germer in the mid-1920's, following a suggestion by Walther Elsasser that electron scattering by the regular configuration of atoms in crystalline solids might reveal the wave nature, just as X-rays had been shown to be waves.

That the Davisson-Germer experiments provided evidence for matter waves was first realized by Born, who gave a talk at the 1926 summer meeting of the British Association for the Advancement of Science that was attended by the American Davisson. Davisson was surprised to see Born presenting Davisson's diffraction curves published many years earlier in *Science* magazine.

De Broglie was invited to give a major presentation on his thesis at the 1927 Solvay conference on Electrons and Photons, but his work was completely overshadowed by the presentation of Heisenberg and Born on the new quantum mechanics.

De Broglie's pilot-wave theory was largely ignored for a quarter century until David Bohm revived it in 1952 in his deterministic, causal, and nonlocal interpretation of quantum mechanics using *hidden variables*. See chapter 30.

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3 De Broglie, 1929, p.247