[Preface: These 3 pages started out as a kind of extended footnote inside a project whose working title is "Making Atoms Real" (unfinished as of 7/15/14). Their "footnote" aspect notwithstanding, I decided that these materials are worth breaking out as a separate file, with its own smaller bibliography appended. The subject behind the playful title ("Quadrille dance...") is this: **1925, 1926, 1927 — what really happened?** You can read a half-dozen 500-page books and try weaving the story together as I did, or you can read these 3 pages and find out the easy way. The story is not pretty or neat, but it is very human, and technical, and nonintuitive. In this highly condensed version of it, every name, every date, every word means something.]

Quadrille dance and shotgun wedding

1925. Heeding the lesson of Bohr's ill-fated orbital theory (1913-1918), Heisenberg is wary (at first) of developing any visual model (Hoffmann pp. 64 and 141); he wants to "get rid of the waves in any form" (Crease & Mann p. 64). Accordingly, with Born and Jordan, Heisenberg sets forth his matrix mechanics formulation of quantum theory (Pais p. 254). (And for this 1925 aspect of his multifaceted contribution, Heisenberg is typecast forever as abstruse — by some.)

1926. Inspired by de Broglie's matter-waves (1923), Schrödinger develops something that seems *relatively* visual (by comparison with Heisenberg's matrices, that is): the wave equation for an electron. (See Hoffmann pp. 74, 109, 141; Pais p. 256.) However, it is Max Born who shows how Schrödinger is 'right for the wrong reason': done right, the wave equation, *psi* ψ, becomes unequivocally abstract: an electron is not 'smeared' per Schrödinger's original concept; rather, it possesses a probability distribution, expressed now by the squaring Einstein's 'ghost field' to $|\psi|^2$ (Pais pp. 259-260, Crease & Mann p. 61, Hoffmann pp. 141-142).

1927. Heisenberg feels competitive pressure from Schrödinger, whose partial differential equations threaten to be more 'popular' than Heisenberg's exotic matrices (Pais p. 255). Consequently, Heisenberg does an about face and now endeavors to find physical meaning in his 1925 formulation — some semantic content, as it were, to ride along on his esoteric syntax. An epiphany at Faelled Park results in his principle of *Unbestimmtheit*, sometimes translated correctly as 'indeterminacy' (e.g., in Hoffmann p. 149, Segrè p. 150) but usually mistranslated as 'uncertainty' (presumably because a six-syllable word is to be avoided at any cost, even when the cost is to sabotage millions of readers' comprehension). Heisenberg presents his *Unbestimmtheit Prinzip* in an article entitled *Über den anschaulichen Inhalt der quantentheoretischen Kinematik und Mechanik* (where *anschaulichen* means 'clear, vivid, graphic' and is translated by Crease & Mann as 'visualizable'; see pp. 64-66). But in his race against Schrödinger, *has* Heisenberg now edged forward to become the The Visual One, by a nose? Yes and no. At the very least, there is an irony to note: Once the dust settles, we recall that the fundamental equation upon which Heisenberg built his indeterminacy principle features *abstract* matrices on the left and the *imaginary* number on the right, not to mention the Planck constant in the numerator: ($pq - qp = \hbar/i$, Crease & Mann p. 65, Pais p. 254). It's a concoction that rates, in Taylor's judgment (pp. 227-228), as "perhaps the most revolutionary equation in the whole of physics." But its potential for *graphical* appeal? Nil. (Moreover, the 1958 passage alluded to earlier brings us full circle to Heisenberg's 1925 stance, which was pointedly anti-visual.)

Next (still in 1927), just as Max Born had argued that Schrödinger was 'right but for the wrong reason', Bohr argues that Heisenberg is right but for the wrong reason. Specifically, Bohr shows Heisenberg how his (Bohr's) would-be argument for refuting indeterminacy (by exploiting post-collision recoil data) is defeated immediately by none other than *the Schrödinger wave equation*. Clearly, quantum theory needs the contributions of *both* Heisenberg *and* Schrödinger, says Bohr. At the prospect of such a denouement to his rivalry with Schrödinger, Heisenberg sheds tears of frustration (Crease & Mann pp. 65-66; Pais p. 261). But Bohr's point is underscored by Pauli who arrives in Copenhagen in June, whereupon he performs a forced reconciliation of Heisenberg to Bohr (Segrè p. 150). Along the same lines, one could say that Bohr, with his 'complementarity principle', performs a shotgun wedding of Heisenberg to Schrödinger in absentia. In any event, the end of the revolution is marked by the fifth Solvay conference, in October of this same memorable year, 1927; Pais pp. 248, 262.

Remark: Similar to the case of Turing 1950, the materials of early quantum theory are so rich and variegated that one can selectively mine them for 'support' of viewpoints that run the gamut. Moreover, no sooner had the dust settled on the revolution itself (1925-1927) than the 'Copenhagen interpretation' began its own decades-long history of inspiring/provoking reactions, sampled next: To Einstein, the Copenhagen interpretation is nothing but "a gentle pillow for the true believer" (Segrè p. 161). To Eric Lerner (who, on pp. 363-364, is temporarily pursuing a socio-political agenda), Heisenberg is responsible for the 'occultism' of the Copenhagen interpretation. In the view of Banesh Hoffmann (p. 144), if we have mental pictures to hold onto, Heisenberg is the one to *thank* for it. In a similar vein, David Bohm cites lectures by *Bohr* as his main source of ideas for building a *physical picture* of the quantum nature of matter. (Strange but true; see Bohm pp. iii and 144n.) No charge of 'occultism' here in the reactions of Hoffmann and of Bohm. Meanwhile, to Abraham Pais, in lieu of the 'Copenhagen interpretation' a more descriptive term would have been the ‘probability interpretation’, i.e., the interpretation (1926) that was due largely to Max Born. (His belated Nobel Prize in 1954 notwithstanding, Born’s name is still mentioned only rarely in the context of Copenhagen; see Pais pp. 260-261 and Hoffmann p. 236.) Finally, this whole Copenhagen mind set, with its insistence on an ensemble that includes an observer and an instrument, strikes some as a provincial human artifact, a distraction from the more pressing issue of quantum effects at the Big Bang (up to 5×10^{-44} seconds), when presumably no one looked and no one measured. (After Taylor p. 398 and p. 253, which resonates with Serber as quoted in Crease and Mann p. 68. Serber, like all of those whose reactions I have logged above, is a physicist.)

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