fact that Werner Heisenberg put forward in 1922 a two-electron atomic model that had electrons moving similarly out of phase and that ascribed a fractional quantum number (½) to the bending mode of the configuration.[1] Although Heisenberg's model predicted the ground-state helium level, which was in excellent agreement with the spectroscopic data, Bohr opposed the model, since a noninteger quantum number was considered sacrilege. For the same reason, Bohr never published his own results. However, the asynchronous two-electron atomic model turned out to be the fertile one, though the corresponding classical configurations can have very complex structure.[2]

References

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■ **Svidzinsky, Scully, and Herschbach reply:** We agree with M. Y. Amusia that a statement we made about the infinite dimension limit is "lacking in rigor." It was intended simply to provide heuristic insight into why, for a wide variety of problems, the large-D limit has proven to be a useful starting approximation to obtain results for $D = 3$.

Amusia's other concerns are answered in a 1975 paper on a D-scaling treatment of helium by David Herrick and Frank Stillinger.[1] They gave a rigorous derivation of the D-dimensional hydrogen atom Hamiltonian, shown as equation 1 in Amusia's letter. That solution applies for $D \geq 2$, as implied in the figure included in box 1 of our article. Herrick and Stillinger also showed that for the correct $D \rightarrow 1$ limit, the Z/r term becomes a δ-function. In D-scaling, contrary to Amusia's assumption, the $D = 3$ form of Coulomb's law can be used for dimensional continuation to the large-D limit. The D-dependent similarity transformation affects the Laplacian, not the potential energy. Both theory and application are amply presented in references given in our article (particularly references 8–11). D-scaling, using just elementary algebra, has attained correlation energies for multielectron atoms with accuracy comparable to or better than conventional electronic calculations.[2]

The papers of Leonard Mlodinow[3] and several other authors, especially the earlier paper by Herrick and Stillinger,[1] fostered the development of D-scaling for electronic structure. Since the kinship of Bohr's model to dimensional scaling was not recognized until 2005, we did not dwell on that history, other than citing the tutorial article by Edward Witten. The treatment of H_2 that Mlodinow cites in the second part of his reference 3 is a deliberately drastic approximation and gives less than 40% of the bond dissociation energy.

As emphasized by Petar Grujic, the bold, perplexing enterprise by Niels Bohr motivated much further work melding classical and quantum mechanics. We note that D-scaling has a distinctive character. It might aptly be termed "semiquantum" rather than semiclassical. Although in the large-D limit the equations become classical, quantum mechanics is hidden in the D-dependent units adopted for distance and energy. At that limit, electrons take fixed positions in the D-scaled space and the first-order correction in $(1/D)$ has them execute harmonic vibrations about those positions. In the prequantum era, such behavior was postulated by Gilbert Lewis and Irving Langmuir,[4] motivated by chemical arguments but disdained by physicists and considered incompatible with the Bohr model.

References

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3. See D. R. Herschbach, *J. Chem. Phys.* **84**, 838 (1986), for analysis of the papers cited in reference 1 of Mlodinow's letter.
4. P. Coffey, *Cathedrals of Science: The Personalities and Rivalries That Made Modern Chemistry*, Oxford U. Press, New York (2008), chap. 5, esp. p. 139.

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