Vignette: Induction

Being a methodical as well as a suggestible person, and having spent the morning reading Francis Bacon, she decided to test the inductive method of reasoning by making lists of former friends and looking for a characteristic common to all of them by which she might arrive at a general law of friendship gone awry.

The names fell into two categories: those she had lost interest in, and those who had lost interest in her. She looked briefly at the column of names of people she had lost interest in, considered calling one or two, then lost interest. The other list, those who had lost interest in her, was baffling, and the only general law she could arrive at was that they were disloyal. This was of course a tautology and surely not what Francis Bacon had been driving at, but then he died of a cold caught while testing his theories of refrigeration by shoving snow into a chicken.

—From *Rameau's Niece*, a novel by *Cathleen Schine* (Plume)

instance as non-interacting, was the stamping ground for armies of theoretically inclined inorganic chemists in the 1960s and '70s, operating under the banner of ligand field theory. One may doubt quite seriously whether any useful purpose is served by going over all this old ground again, and much of the content of the early chapters of Kahn's book is easily accessed through the standard textbooks of Ballhausen and Figgis, not to mention the classic works of Condon and Shortley and Griffith. The contents of most of the extensive appendixes can also be found in these books. Novelty begins to emerge from chapter 4 onward, when interactions between metal ions in dimeric or more extended centers are treated. A wealth of formal cases is considered (binuclear, trinuclear—symmetrical and unsymmetrical—isotropic and anisotropic interactions) that will helpfully guide chemists toward rationalizing properties of the multifarious compounds turned up adventitiously even by what we sometimes call "directed" syntheses.

More penetrating in terms of rationalizing interaction mechanisms are the descriptions of the various approaches starting from molecular orbital or valence bond limits initiated by Anderson 30 years ago and systematized for the use of solid state chemists by Kanamori and Goodenough. Kahn shows convincingly, and in language familiar to chemists, how what he charmingly labels the "rustic" approaches to conjugated molecules like the Huckel model fail completely as a starting point for rationalizing magnetic interactions. He sets out the formalism of two apparently disparate but in the end equivalent models based on "natural" and "orthogonalized" magnetic orbitals and coins some useful phrases such as the "active electron approximation." And yet the nagging thought persists that we have been here before, which brings me back to my original question.

The distinguishing features of molecular magnetism as expounded by Kahn are, first, that the materials in question contain only localized magnetic electrons (that is, the book deals only with magnetic insulators) and, second, that for the most part they have quite low point and space group symmetries as a result of elaborate and often quite beautiful molecular architectures brought about by the tailor-made organic ligands. Physicists often use the word "zoo" in such cases to express their horror at having to search for first principles among such complexity, but in the present case the principles have been available for a long time. Indeed, in his preface Kahn pays tribute to Van Vleck and Anderson, to whose names the others mentioned above should certainly be added. Where then does that leave "molecular" magnetism? In my view there is a seamless web of increasing structural complexity from binary oxides to metal-organic clusters and multi-metallic enzyme active sites. The central themes of molecular magnetism are then (as I just stated) some beautiful and subtle chemistry, enabling coordination geometry and crystal packing to be tuned to a fine degree, and the fact that these compounds are unusual among magnetic materials in being transparent and colored. Two deficiencies of this book are that it says nothing about the way to actually make molecular magnets or about their electronic excited states. Twenty years ago we found a class of organic-soluble transparent magnets that changed color at the Curie temperature—what fun! Kahn's book is Cartesian and didactic: the fun (and there is plenty of it) is mostly left to the imagination.

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Engineering Lessons

Design Paradigms. Case Histories of Error and Judgment in Engineering. HENRY PETROSKI. Cambridge University Press, New York, 1994. xii, 209 pp., illus. $42.95 or £30; paper, $17.94 or £12.95.

Powerful as today's ubiquitous computational models are for analysis, conceptual design still, as Henry Petroski puts it, "involves the human mind in fundamentally the same way it did for the first builders [relying] more on [mental] pictures than on words or numbers" (p. 11). We may not yet be able to point to a spate of recent writings concerned with the slighting of this cornerstone of design in American engineering education, but the publication of *Design Paradigms* following on Eugene Ferguson's *Engineering and the Mind's Eye* (1992) may well augur such a trend.

For Petroski, professor of civil engineering at Duke University, "The single most fruitful source of lessons in engineering judgment exists in the case histories of failures, which point incontrovertibly to examples of bad judgment and therefore provide guideposts for negotiating around the pitfalls in the design process itself." Sound engineering judgment, he argues, can also be learned from studying the "great engineers, who by their works have demonstrated that they possessed impeccable judgment, which has more often than not come from their critical study of failures or near-failures" (p. 122). In this vein, Petroski makes the case for investigating classic and historical case studies rather than recent design failures, the analysis of which is often complicated by ongoing litigation and distortions or, even more critically, by court-imposed secrecy.

The historical studies, then, are taken mainly from civil or structural engineering, ranging from the pitfalls of transporting large column components in ancient Greece to the failure, from aerodynamic flutter, of the Tacoma Narrows Bridge in 1940. The critiques tend to be rather compact, but they can be augmented by consulting publications listed in the ample bibliography. Succinctness may also account for Petroski's having omitted, in recounting Galileo's description of Renaissance shipbuilders taking extra precautions in launching larger ships because of scale effect (pp. 54–55), that Galileo also lauded these "artisans . . . who, through observations [of failures or near-failures] handed down by their predecessors as well as those which they attentively and continually make for themselves, are truly expert and whose reasoning is of the finest" (*Dialogues Concern-*

ing Two New Sciences, University of Wisconsin Press, 1974, pp. 11–13). Indeed, Galileo's commentary provides the key for understanding the basis of prescientific engineering successes as well as grounds for Petroski's assertion that "engineering is part art" (p. 183).

Unfortunately, the editing of the text is disappointing. Several chapters read like stand-alone articles little altered for publication in book form: key concepts as well as historical background material, already fully elucidated in earlier chapters, are irritatingly reiterated. Nonetheless, *Design Paradigms* provides a cogent argument for reintroducing engineering history—albeit taught by engineering faculty who can interpret the underlying technological inferences—into primary engineering study. Once considered an essential part of the engineering curriculum, such courses were forced aside early in the 20th century to make way for the more advanced mathematics and engineering analysis courses deemed far more important. In addition to providing needed instruction in engineering judgment and design, as Petroski indicates, well-planned courses in engineering history might also be used to illustrate the vital process of transferring ideas from one field to another.

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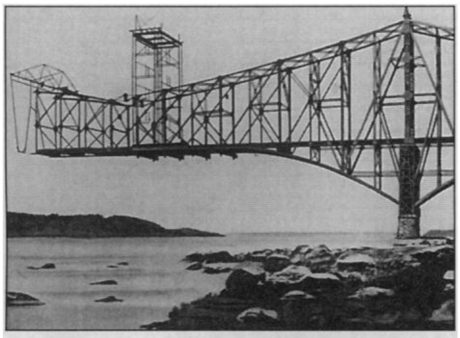

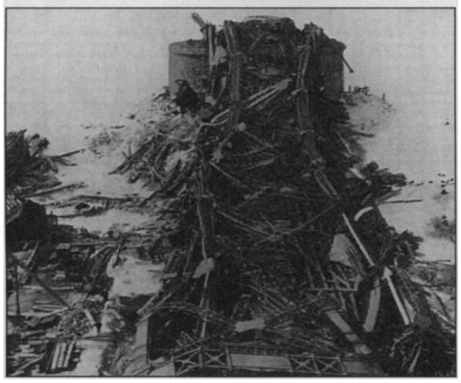

The Quebec Bridge across the St. Lawrence River, under construction in 1907 and after collapse the same year. "Although the span of the Quebec Bridge was essentially the same as that of the colossal Firth of Forth Bridge . . . the belief that the stocky Forth Bridge was very much overdesigned generated a confidence that paring down the members of the Quebec span carried little risk. In effect, the bones of the bridge were too slender to carry its own weight. . . . The structure was subsequently redesigned . . . , and the (second) Quebec Bridge stands today . . . as a symbol to Canadians of perseverence in the face of adversity." [From *Design Paradigms*; Canada Department of Railways and Canals report, 1919]

Interpretations

The Undivided Universe. An Ontological Interpretation of Quantum Theory. D. BOHM and B. J. HILEY. Routledge, New York, 1993. xii, 397 pp., illus. $29.95 or £25.

When the late David Bohm devised his hidden-variable version of quantum theory in 1952, which is experimentally indistinguishable from the conventional one, he accomplished a feat most physicists thought impossible, because they believed that Von Neumann had ruled out such a possibility. This started John Bell on his researches, which not only found the limitations in Von Neumann's proof but also led to Bell's theorem, which spawned a whole new field of experimental and theoretical work.

So now it is over 40 years later and most physicists are still barely aware of the fact that there exists a viable deterministic interpretation of quantum theory. New students won't even find the theory mentioned in their texts. A typical reaction from working physicists is, "The usual interpretation works, so why do I have to learn another one?" This from physicists who in classical theory pride themselves on knowing the Newtonian, Lagrangian, Hamiltonian, and Hamilton-Jacobi approaches!

The answer of course is that each approach offers its own set of insights into the same material. At the very least, the Bohm interpretation ought to make one skeptical of the claim that probabilities are the essence of quantum theory. Rather, the feature the two interpretations strongly share is non-locality.

This book, by Bohm and his long-time associate Basil Hiley, is an attempt to make the Bohm theory plausible. They call it the ontological interpretation, to emphasize that individual events can be tracked down to particles following trajectories, and in that sense at least the theory is conceptually closer to classical theory. However, besides the ordinary force potential, there is also a "quantum potential," which can cause the particles to suddenly veer aside to produce interference patterns and the like. The quantum potential can act instantaneously over great distances and acts without being in turn acted upon, giving phenomena their non-local nature. The analogy the authors give is that of a radio signal that can control a large ship from great distances. It is information, not energy transport, that is important here.

Bohm and Hiley also call their version a causal interpretation, since one can follow events in detail beyond what one can actually measure, as contrasted to the usual interpretation, where one does not ask questions about mechanisms one cannot verify. I think "causal" here is a misleading term, however, since the quantum potential can act like a *deus ex machina*, disrupting any effectively predictable behavior.

The book is loaded with clever insights, as anyone familiar with Bohm's writings can expect, and there are long and sometimes deep philosophical asides on many aspects of the subject. There is also a good and critical discussion of other recent interpretations of quantum theory, such as the "many worlds" interpretation, the Ghirardi-Rimini-Weber interpretation, "decoherence," and the "consistent history" cosmology of Gell-Mann and Hartle. The book is well worth it for these add-ons alone, but in fact this is a very important book, an attempt to open the minds of physicists to understand that what they are used to is not necessarily uniquely true. There is also another good recent book on this subject, Peter R. Holland's *The Quantum Theory of Motion* (Cambridge University Press), which tends to be more like a textbook.

There are certain problematical aspects to the theory, which from the conventional point of view seem like drawbacks but from the standpoint of the theory itself seem like inevitable consequences. One of these is the relativistic extension, which violates Lorentz invariance for individual events, though it preserves it over ensemble averages, so that it gives the usual experimental results. Ugly, one says. But the authors point out that if non-locality exists for individual events, this necessitates a breakdown of relativity, at this level. So who's to say? Maybe all the infinities in field theory come from a too-rigid insistence on pointwise Lorentz invariance. I think it would be foolish to prejudge this point, even though it runs counter to one's preferences.

Now that there are two books clearly explaining the theory, a development made possible by recent advances in understanding the application of the theory to standard problems, it will seem inexcusable if future textbooks on quantum theory continue to make believe that this interpretation doesn't exist. In the future, one will have to come to terms with its insights. And if you are a fan of Bohm's book on