thesis

A quantum of history

Michelle Francl wonders how much time chemists should spend learning history.

Seen from afar, it could have been the opening scene for a movie starring Julia Roberts. It's a cool crisp autumn day on a classic college campus, the trees blazing red and orange. A young faculty member is walking up the steps to a Gothic stone building chatting, companionably perhaps, with her senior colleague. Cut to the close up. "What are you teaching them in your course?" the more experienced academic grumbles. "They don't know anything about chemistry!"

My colleague's litany of complaints about my course content would have been more worrisome if she were a chemist and not a historian. She was aghast that junior chemistry majors could not rattle off who had discovered oxygen or when, or the details of the phlogiston controversy. I wondered (not aloud, I wasn't tenured at the time), whether she could write down the Schrödinger equation for oxygen, or manipulate the Maxwell relations, as such things seemed as important to her course as the dates and historical figures were to mine. I countered that my first priority was conveying essential principles of chemistry, not key historical facts, but I don't think I convinced her that a thorough historical framework was a frill, not a fundamental, in my discipline.

Fast forward two decades and I have a fellowship in the history of science. This semester I am teaching a history course in the morning and quantum mechanics in the afternoon. There are moments when this makes me wonder if I'm now my own enemy. At the very least, it has given me double vision. These days I read chemistry — be it the primary literature, review articles or textbooks — as both a scientist and a historian. The historical subtext of 'who and why' interest me as much as the 'how and what' that constitute the primary chemical narrative. But as I prepared to teach quantum mechanics this autumn, I thought again of my colleague's question: what am I teaching them in my course? What historical background, if any, should a chemist have mastered?

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Over the years, although my interest in the historical and sociological context in which chemistry sits has grown — and in spite of the fact that it is my particular field of interest — I have taught less and less about the historical development of quantum mechanics. Yet when browsing the introduction to quantum mechanics in nearly any general or physical chemistry textbook, you will find that the development of this topic, in marked contrast to chemical kinetics or organic synthesis or virtually any other area, is most often done in the context of the field's history. The story typically begins with blackbody radiation and Planck's brilliant resolution of the UV catastrophe by the introduction of quantization. Continuing at a speed approaching that of light, the narrative then often barrels through Einstein's explanation of the photoelectric effect and finally winds up with Schrödinger's construction of the wave equation. Only then does one get down to the details of applying quantum theory to the things of most interest to chemists, namely molecules. And these are applications that can be effectively deployed without any understanding of blackbody radiators or even photoelectric phenomena!

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Why, I wonder, is it that we routinely teach quantum mechanics, at the very elementary as well as more advanced levels, from such a firmly historical perspective? Is it merely a persistence effect — this is the way I heard it taught, so this is how I will frame it when I teach — or are there pedagogical aspects unique to quantum mechanics that keep it so firmly attached to its history?

A case can certainly be made for the persistence hypothesis. The structure and content of physical chemistry textbooks has been remarkably conserved over time. A case in point: first order chemical kinetics is illustrated by the same reaction, the decomposition of N_2O_4, in the textbook I currently teach from, the textbook my mother used in 1953, and in the 1931 textbook a predecessor at Bryn Mawr College, Frederick Getman, wrote. The development of quantum mechanics in physical chemistry texts has been solidly historical for at least five decades. The chapter on quantum theory in Farrington Daniels' 1952 edition of *Outlines of Physical Chemistry*[1] plunges directly into a three-and-a-half page exhaustive description of what was known about blackbody radiation in the nineteenth century, without so much as a prefacing statement regarding the reasons for exploring that ground. McQuarrie and Simon devote the entire first chapter of the current edition of their physical chemistry text to a history of the developments that led to quantum physics[2]. By way of comparison, both texts leave history entirely out of their introduction to thermodynamics, content to begin with definitions of key terms such as heat, work and energy, without any reference to how they arose.

It could be that quantum mechanics as a field is newer than either thermodynamics or organic synthesis, the history is fresher, and the key figures were personally known, if not to this generation of faculty, to some of our teachers. There are notes from Albert Einstein and Linus Pauling in my mother-in-law's files, for example. Perhaps as personal memories fade of Rutherford, Einstein and Heisenberg, historical reference to their work will fade from the texts. I would suggest, however, that such attenuation is unlikely to occur. Sixty years ago, in their presentation of osmosis, Prutton and Maron's physical chemistry text[3] refers to 'celebrated' researchers such as E. G. J. Hartley and the Earl of Berkeley. Who, you say? Hartley and his collaborator were contemporaries of Einstein and Planck. Their paper[4] describing what would become the standard method of measuring osmotic pressures was published in 1904, the year before Einstein's *annus mirabilis* and four years after Planck's work on blackbody radiation was made public, yet the tale of their exploits is no longer recounted in textbooks.

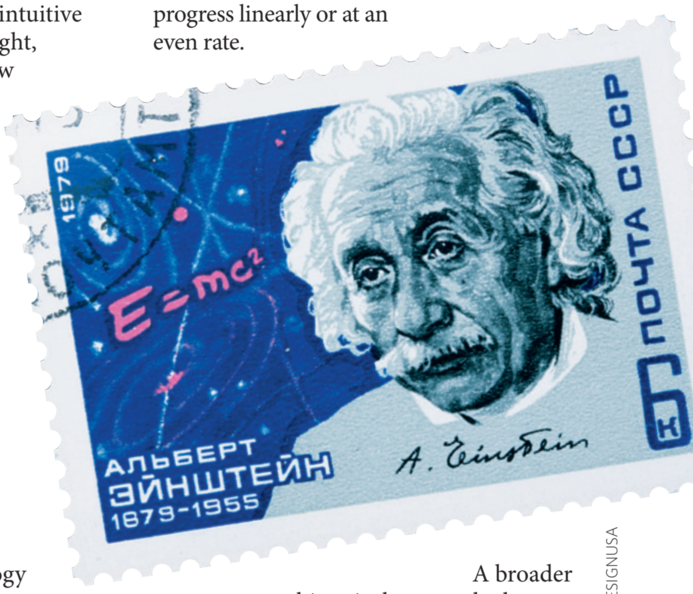
Of course, the discovery of a robust method for measuring osmotic pressures did not turn physics upside down in quite the same way as Einstein's proposition that light was quantized. Perhaps we require a constant recounting to make clear the necessity of developing a theoretical framework which, in many instances, runs counter to our everyday experience — even today we don't quite believe quantum mechanics. Consider Joel Hildebrand's general chemistry text, in which a sudden digression into the analysis of possible frameworks for introducing material in a textbook appears in the middle of his discussion of atomic structure[5].

Hildebrand, one of the first physical chemists in the United States, suggested there were three ways of approaching a topic: logically, chronologically and psychologically. You can construct a tight rational argument that leads directly to the desired conclusion; you can present the evidence as it was historically accumulated, presuming that the schema that once persuaded the cognoscenti will equally well persuade the less enlightened; or you can pull the reader repeatedly into the actual practical workings of a theory until they see its utility, even if they cannot acquiesce at first — or indeed ever — to its rationality.

This midstream digression into pedagogical theory makes me suspect that Hildebrand was worried that his reader would dismiss the often counterintuitive claims of quantum physics outright, and was thinking hard about how to convince students of the validity of quantum mechanics, as well as its value to chemists. I don't need to be regularly persuaded that thermal equilibrium will result when a hot object and a cold object come into contact; I am reminded every time I forget a cup of tea on my desk. On the other hand, when it comes to the diffraction of helium atoms, a rational explanation may feel discordant, making the chronological or psychological approaches more appealing for an instructor.

I wonder if more than pedagogy drives our choice to push the history of quantum mechanics to the fore. It is a compelling and compact narrative of discovery. The problems are clear. The cast of characters is small and colourful: the iconic genius, Einstein; Schrödinger and his mistresses; Bose, who independently derived Planck's radiation law after he made an error in a lecture. Like the heroic tales of the Greek gods, the discovery of quantum mechanics becomes an archetype for scientific research, a noble tale of the success of theory. If so, we tread a risky path. The reality of science is often far less clear, far more tangled. If this is the only tale of discovery we tell students, we leave them ill prepared to work through the usual knots that research problems entail.

Given the quantum mechanical tools — practical, theoretical and computational — that we can now wield, I would argue that we should shift the focus off the historical in quantum chemistry, and take up Hildebrand's psychological approach with its emphasis on the pragmatic. This is not to say we should entirely ignore the historical antecedents of the chemistry we teach. A fuller picture of the ebb and flow of progress in discovery helps to set up appropriate expectations for students in research. Research does not always lead where you think it might, nor does it necessarily progress linearly or at an even rate.



A broader historical approach also offers a stronger narrative arc. Having a data point beyond the present may enable young researchers, without a personal history in the field, to better see where their own work could go.

These days in my own teaching and research, I'm encouraging students to become familiar with the more prevalent examples of discovery narratives, namely those that are not particularly linear in nature. I tuck short paragraphs about key discoveries onto the end of problem sets, and set new material in a brief historical context. I prod research students to read the earliest literature on their project, and to read some of the 'dead-ends.' I suspect my long-ago history colleague would still think I'm failing my students in not asking them to commit key dates to memory, but she might be pleased to know that they heard something of Lise Meitner's (who discovered nuclear fission) contributions to organic chemistry and the development of matrix mechanics. I wonder if she'd be as interested in learning more about the Maxwell relations? ❐

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