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Just a Theory: The Atomic Theory Debate and High School Chemistry, 1905–1917

ABSTRACT

This paper considers educators' debates over the proper place of the atomic theory in American and Ontario high schools during the first decade of the twentieth century, in the context of emerging, historic research on the nature of matter. In 1905, University of Toronto chemist William Lash Miller distributed a booklet instructing Ontario teachers how to teach chemistry without the atomic theory. According to Lash Miller and his Toronto colleagues, who edited a new textbook in 1906, teaching the atomic theory to beginners bred flawed and fuzzy reasoning. Lash Miller was a student of Wilhelm Ostwald, who famously doubted the reality of atoms until convinced by Jean Perrin's 1908 experiments on Brownian motion. This paper shows that limiting the role of the atomic theory was part of an effort, both in Ontario and in the United States, to reorient the high school curriculum toward the expanding discipline of physical chemistry, specifically, a vision of physical chemistry indebted to Ostwald. Like the Toronto chemists, Chicago physical chemist Alexander Smith lamented high school textbooks' overreliance on the atomic theory and promoted the use of laboratory terms. Both Lash Miller and Smith met with resistance from high school teachers, who defended the teaching of the atomic theory and advocated a competing view of beginners' pedagogy. These debates were not settled primarily by appeals to evidence, but instead revolved around differing views of the needs and abilities of high school students.

KEY WORDS: atomic theory, textbooks, physical chemistry, science education, high school chemistry, Wilhelm Ostwald, William Lash Miller, Alexander Smith

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The following abbreviations are used: AO, Department of Education text book correspondence and memoranda, Archives of Ontario; OEA, Ontario Educational Association; *POEA*, *Proceedings of the Ontario Educational Association*; *SSM*, *School Science and Mathematics*.

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INTRODUCTION

At the 1907 meeting of the Ontario Educational Association (OEA), a conference of educators and administrators held annually in Toronto, a high school teacher named George Cornish addressed his colleagues in the Natural Sciences Section on a topic bound to spark controversy. His lecture was titled, "Should the Atomic and Molecular Theories Be Abolished from the High Schools?," and his answer was an emphatic *no*. In his address, Cornish accused a group of chemistry professors at the University of Toronto of conducting a zealous crusade against the atomic theory and successfully pressuring the Ontario Department of Education to drop it from the high school chemistry curriculum.

Cornish singled out professor William Lash Miller, who had recently circulated among the province's science teachers a chemistry teaching guide that denounced the atomic "hypothesis" and outlined how to teach the high school course without reference to atoms and molecules. Cornish's harshest criticism was reserved for a new high school chemistry textbook, *Chemistry for Schools*, published in 1906 and edited by Lash Miller and his Toronto colleagues Frank Kenrick and F. B. Allan. The new textbook avoided all mention of atoms and molecules except for a two-page appendix that blamed the atomic hypothesis for causing the "one-sided" development of chemistry. Cornish accused the textbook of "outlandish terminology" and "narrow-minded quibbling." His analogies were colorful, pugnacious, and clichéd. Trying to teach or understand chemistry without reference to the atomic theory was like curing a toothache by cutting off one's head. It was like the man who set his house on fire to roast his pig. It was like acting *Hamlet* without the Prince of Denmark. Such teaching, Cornish alleged, would give students a narrow and distorted view of chemistry that would take years to rectify. Professor Lash Miller himself was in the audience, and the meeting minutes note mildly that the address was followed by "very interesting discussions."[1]

The scandalized tone of Cornish's protests belied the longstanding controversy that had surrounded the role of atomism in pedagogy. References to the atomic theory were famously redacted from many French chemistry textbooks in the mid-1830s. In the latter decades of the nineteenth century, many

1. G. A. Cornish, "Should the Atomic and Molecular Theories Be Abolished from the High Schools?" *POEA* 46 (Toronto: William Briggs, 1907), 198–207; "Minutes of the Natural Science Section," *POEA* 46 (Toronto, William Briggs, 1907), 18–20.

chemists balked at the ontological implications of the atomic theory and disagreed about its methodological and pedagogical value. The nineteenth-century atomic debates have been extensively chronicled; what is less well known is that the atomic theory remained a point of contention in Canada and the United States in first decade of the early twentieth century.[2] Although Cornish painted Lash Miller and his colleagues as an isolated and recalcitrant minority, the role of the atomic theory in high school chemistry was in fact an ongoing topic of debate among American science educators. The rise of physical chemistry in the late nineteenth century had reinvigorated disputes about atomism, as some physical chemists—most notably Wilhelm Ostwald—promoted a thermodynamic approach to chemistry that rejected a mechanistic view of nature. The steady stream of students who populated Ostwald's celebrated laboratory in Leipzig, many from Canada and the United States, became promoters of physical chemistry and established their own physical chemistry laboratories. A few espoused a cautionary view of the atomic theory, even if most did not embrace Ostwald's concomitant devotion to energetics.[3]

University of Toronto chemist William Lash Miller was one such disciple. He worked in Ostwald's laboratory in 1890 and 1892, a period when Ostwald

2. On nineteenth-century atomic debates, see, for example, Alan J. Rocke, "Epilogue," in *Chemical Atomism in the Nineteenth Century: From Dalton to Cannizzaro* (Columbus: Ohio State University Press, 1984), 313–40; Alan J. Rocke, "The Atomic War," in *Nationalizing Science: Adolphe Wurtz and the Battle for French Science* (Cambridge, MA: MIT Press, 2001), 301–31; Mary Jo Nye, introduction to *The Question of the Atom: From the Karlsruhe Congress to the First Solvay Conference, 1860–1911* (Los Angeles: Tomash Publishers, 1984), xiii–xxxi; W. H. Brock and D. M. Knight, "The Atomic Debates," in *The Atomic Debates: Brodie and the Rejection of the Atomic Theory*, ed. W. H. Brock (Leicester: Leicester University Press, 1967), 1–30; José Ramón Bertomeu Sánchez and Antonio García Belmar, "Atoms in French Chemistry Textbooks During the First Half of the Nineteenth Century: The *Eléments De Chimie Médicale* by Mateu Orfila (1787–1853)," *Nuncius: Annali Di Storia Della Scienza* 19, no. 1 (2004): 77–119; Antonio García Belmar, José Ramón Bertomeu Sánchez, and Bernadette Bensaude-Vincent, "The Power of Didactic Writings: French Chemistry Textbooks of the Nineteenth Century," in *Pedagogy and the Practice of Science*, ed. David Kaiser (Cambridge, MA: MIT Press, 2005), 219–51; Catherine Kounelis, "Atomism in France: Chemical Textbooks and Dictionaries, 1810–1835," in *Communicating Chemistry: Textbooks and Their Audiences, 1789–1939*, ed. Anders Lundgren and Bernadette Bensaude-Vincent (Canton, MA: Science History Publications, 2000), 207–231.

3. John W. Servos, chapter 2 in *Physical Chemistry from Ostwald to Pauling: The Making of a Science in America* (Princeton, NJ: Princeton University Press, 1990), 46–99. On Ostwald's energetics, see Bernadette Bensaude-Vincent, "Revisiting the Controversy on Energetics," in *Wilhelm Ostwald at the Crossroads Between Chemistry, Philosophy, and Media Culture*, ed. Britta Görs, Nikos Psarros, and Paul Ziche (Leipzig: Leipziger Universitätsverlag, 2005), 13–28; Niles R. Holt, "A Note on Wilhelm Ostwald's Energism," *Isis* 61, no. 3 (1970): 386–89.

was busy translating J. Willard Gibbs and warning his students about the dangers of relying on the atomic theory.[4] Lash Miller returned to Toronto "ablaze with the possibilities of the new physical chemistry, his discovery of thermodynamics, and especially his introduction to the works of Willard Gibbs," in the words of a former student.[5] Around 1900, after his promotion to associate professor, Lash Miller took an active interest in Ontario's high school chemistry course. Over the next seven years, he drafted a new curriculum, published a teaching guide for the province's high school teachers, and co-edited *Chemistry for Schools*. In all these projects, he drew on principles of physical chemistry, denounced the atomic theory, and argued that modern teaching methods should avoid hypotheses. Lash Miller's pedagogical writings were notable for their uniquely strenuous pronouncements against the atomic theory, but he and his Toronto colleagues were not alone in asserting that the atomic theory needed to be minimized or eliminated in beginner textbooks. The role of the atomic theory in high school chemistry repeatedly came up both in the OEA and in the pages of *School Science and Mathematics*, the main American forum for discussions of science pedagogy.[6] Most notably, American physical chemist Alexander Smith spoke out against what he saw as the exaggerated place of atoms in elementary chemistry teaching.

This paper examines Lash Miller's effort to reshape Ontario's high school chemistry curriculum and his ultimately unsuccessful attempt, with his Toronto colleagues, to introduce a new textbook that propounded his particular brand of antiatomism. More broadly, it looks at how educators in both the United States and Canada clashed over the pedagogical value of the atomic theory at a unique juncture in both the development of the atomic theory and the growth of secondary school education. In the first decade of the twentieth century, Ostwald was publicly challenging the explanatory value of the atomic theory and questioning the physical reality of atoms—but by 1909, he would concede the existence of atoms, convinced by Jean Perrin's experiments on Brownian motion. Meanwhile, high school systems were in rapid expansion in

4. Servos, *Physical Chemistry* (ref. 3), 162.

5. L. E. Westman, "William Lash Miller: A Brief Series of Comments on the Man and His Mind, the Teacher and His Times," *Canadian Chemistry and Process Industries* 24 (Sep 1940): 476–478.

6. Discussions of the atomic theory in the OEA extend back to 1898, when William Pike, outgoing chair of the University of Toronto chemistry department, made a spirited case for putting the atomic theory front-and-center in textbooks. Seven years later, Lash Miller argued the very opposite. William H. Pike, "The Teaching of Chemistry," *POEA* 37 (1898): 145–51.

both Canada and the United States, and under the pressure of growing enrollment and a widening student body, the purpose of science teaching was repeatedly called into question.[7] The story of chemistry teaching and the atomic theory in these early years of the twentieth century highlights the ongoing tensions between high schools' role as sites of disciplinary reproduction and their role as providers of general education.

Pedagogical debates about the atomic theory were transparently about scientific authority, though rarely explicitly so. As university chemists looked to high schools for discipline building, wrangling over the contents of the high school chemistry curriculum became a proxy war over scientific methodology. While chemistry professors enjoyed relative autonomy in their university courses, those campaigning for changes in high schools had to make their case to teachers, administrators, and government officials. Debates about atomism were therefore also disputes over *pedagogical* authority, steeped in rhetoric about the needs of beginner learners. Ontario high school teacher George Cornish vehemently denounced the interventions of Lash Miller and his colleagues, and Kansas City high school teacher Fredus Peters challenged University of Chicago chemist Alexander Smith in the pages of *School Science and Mathematics*.

Disputes about the pedagogical role of the atomic theory, proper scientific method, and the distinctive needs of beginners' minds all converged on the question of hypotheses. The atomic theory became a stand-in for theory writ large. Disputants agreed that the minds of beginners presented needs that were distinct from those of advanced students and experts, and that could only be met by specific, restricted uses of theory, including the atomic theory. High school chemistry—chemistry *for beginners*—represented both the essentials and the fundamentals of the discipline. It represented how a growing educated public would perceive chemistry and laid the groundwork for students' potential university studies. The place of the atomic theory in the high school curriculum therefore held tremendous symbolic value, particularly for those, like Lash Miller and Smith, who stressed its hypothetical status and contested its primacy in chemistry. As John Rudolph has argued, the high school

7. From 1890 to 1910, American high school enrollments rose by 13% per year, dramatically outpacing population growth; see John L. Rudolph, "Epistemology for the Masses: The Origins of 'The Scientific Method' in American Schools," *History of Education Quarterly* 45, no. 3 (2005): 341–76, on 356–57. In Canada, high school enrollments more than doubled from 1883 to 1904, and Toronto's high schools saw an eightfold increase from 1870 to 1900; see Robert M. Stamp, *The Schools of Ontario, 1876–1976* (Toronto: University of Toronto Press, 1982), 40.

classroom is a space where images of scientific practice have been created and disseminated, and where "competing interest groups" have vied for authority as these images are crafted for new publics.[8] This paper shows how the atomic theory, the object of heated disputes throughout the nineteenth century, emerged as the focus of a new clash of interest groups in the first decade of the twentieth century—this time, over its place in the high school classroom.

ANTIATOMISM AND CHEMISTRY PEDAGOGY: A RETROSPECTIVE

In 1907, when Cornish gave his fiery talk to the OEA, antiatomist pedagogy already had a storied history. For much of the nineteenth century, chemists could not agree about how to calculate elemental weights, and rival approaches had yielded distinct sets of values and notation systems. All chemists agreed that chemically indivisible units persisted through chemical reactions—Alan Rocke calls this "chemical atomism"—but did not agree that this phenomenon could be attributed to physical, indivisible atoms. The Karlsruhe conference of 1860 largely put an end to the confusion of rival systems. Atomic weights beat out rival equivalents, enshrining the set of formulas and weights we are familiar with today. However, even though atomic weights eventually won the day (and even though *chemical* atomism had been noncontroversial all along), disputes about *physical* atomism persisted into the late nineteenth century.[9]

Pedagogy sharpened these disagreements. Chemists worried about the images of science that students would receive in textbooks and classrooms. As Mary Joe Nye has observed, "The expository or demonstrative integrity of the atomic theory was a central issue in the atomic debates." One set of concerns centered on students' exposure to controversial theories, which might undermine their faith in chemistry. Another centered on the kind of epistemology that was suitable for beginners. It was common to argue that although the atomic theory might be useful for chemists, it did not teach the reasoning skills that *students* needed to learn.[10] Invoking such justifications, some textbook authors excised all reference to atoms. The case of French textbooks is

8. John L. Rudolph, "Turning Science to Account: Chicago and the General Science Movement in Secondary Education, 1905–1920," *Isis* 96, no. 3 (2005): 353–89, on 358.

9. Rocke, "Epilogue" (ref. 2); Rocke, "The Atomic War" (ref. 2).

10. Nye, *Question of the Atom* (ref. 2), xxv.

particularly well known. In France, official syllabi avoided reference to the atomic theory from 1837 onward, and many influential textbook authors followed suit. Marcellin Berthelot's overt opposition to atomism kept atoms off the official curriculum until his death in 1906.

Authors who opted to remove the atomic theory from their textbooks did so for a variety of reasons, including concerns emerging from new research, but *justified* this move by propounding a particular vision of beginners' pedagogy. They denounced the use of speculative hypotheses in the prefaces of their textbooks, claiming that beginners needed to be groomed in a careful empiricism suited to untrained minds. These authors were not necessarily themselves antiatomists nor positivists; in fact, some took for granted the corpuscular nature of matter.[11] As Bernadette Bensaude-Vincent has argued, textbook authors' positivist statements should therefore be seen as rhetorical stances: educators articulated their own "textbook positivisms" that specified a strict empiricism tailored to beginner learners.[12]

Early twentieth-century disputes about teaching the atomic theory in Ontario and the United States rehashed much of this rhetoric, but the antiatomism that undergirded these disputes was inherited not from France but from Germany. In the 1890s, a new kind of antiatomism had emerged under the banner of Wilhelm Ostwald. For Ostwald, thermodynamics obviated the need for atomism, which had been supplanted by energetics. In 1895, Ostwald delivered a speech that denounced mechanistic materialism, arguing that matter was imaginary and that energy was the real medium of exchange in nature. Weathering the heavy criticism that greeted his energetics program, Ostwald reiterated his arguments in his Faraday Lecture of 1904. Bolstered by research showing that Gibbs' phase rule could be applied to stoichiometry, Ostwald confidently announced that the laws of chemical combination could be derived without postulating the existence of atoms. Likewise, elements, compounds, and solutions could be defined without reference to atoms.[13]

11. Belmar, Sánchez, and Bensaude-Vincent, "Didactic Writings" (ref. 2), 239; Sánchez and Belmar, "Atoms" (ref. 2), 98; Kounelis, "Atomism in France" (ref. 2), 215.

12. Bernadette Bensaude-Vincent, "Atomism and Positivism: A Legend About French Chemistry," *Annals of Science* 56 (1999): 81–94.

13. Nye, *Question of the Atom* (ref. 2), xxii–xxiii; for Ostwald's 1895 Lübeck address, see 335–54. On Ostwald's energetics program, see Bensaude-Vincent, "Revisiting" (ref. 3); Holt, "Ostwald's Energism" (ref. 3); Erwin N. Hiebert, "The Energetics Controversy and the New Thermodynamics," in *Perspectives in the History of Science and Technology*, ed. Duane H. D. Roller (Norman: University of Oklahoma Press, 1971), 67–86.

Ostwald's laboratory in Leipzig attracted students like Lash Miller who were enthusiastic about the new physical chemistry.[14] Ostwald, Svante Arrhenius, and Jacobus Henricus van 't Hoff boldly announced the inauguration of the discipline of physical chemistry in 1887, when they founded the *Journal for Physical Chemistry* (*Zeitschrift für physikalische Chemie*). They claimed to be doing something fundamentally new in chemistry. Physical chemistry, they claimed, promised to uncover fundamental laws and place chemistry on a solid quantitative and theoretical foundation.[15] Ostwald argued that this project called for an approach that recognized the primacy of the chemical reaction. New areas of investigation included reaction rates, reversibility and irreversibility of reactions, the chemistry of solutions, and electrolytic dissociation, all with a focus on quantitative methods.[16]

As Ostwald's disciples returned to America, physical chemistry quickly found a foothold in the expanding university system. Some believed that this exciting new approach to chemistry was also poised to transform high school chemistry.[17] Former Leipzig student Harry Clary Jones of Johns Hopkins, for example, insisted that teaching ions was preferable to teaching atoms, since the chemistry of ions "corresponds to the facts." Jones proclaimed that the modern methods of physical chemistry demanded a renovation of high school science teaching. "The time has undoubtedly come," he wrote,

> when the whole subject of the teaching and study of general chemistry is undergoing a reformation which is radical. The purely descriptive chemistry is giving way to a science of chemistry which is the analogue of the science of physics. Great masses of more or less isolated facts are being correlated and referred to a few wide-reaching generalizations. In order that the chemist of today, and especially of tomorrow, should be properly trained, it is all

14. Lash Miller spent two summers in Leipzig. His research in Ostwald's laboratory focused on the conversion of chemical energy into electrical energy. John T. Stock, "William Lash Miller: Latent Heat and Electrode Potential," in *Ostwald's American Students: Apparatus, Techniques and Careers* (Concord, NH: Plaidswede, 2003), 43–48.

15. Arrhenius and van 't Hoff did not share Ostwald's views about the atomic theory. In fact, Arrhenius privately tried to change Ostwald's mind and was relieved when, in 1908, Ostwald eventually did. See Elisabeth Crawford, "Arrhenius, the Atomic Hypothesis, and the 1908 Nobel Prizes in Physics and Chemistry," *Isis* 75, no. 3 (Sep 1984): 503–22.

16. Servos, chapter 1 in *Physical Chemistry* (ref. 3), 3–45.

17. Not all concurred, however, that physical chemistry was suitable for beginners. A 1903 survey of chemistry teachers and professors, including several Leipzig graduates, reveals disagreement. See "Symposium on the Teaching of Physical Chemistry to Beginning Students," *SSM* 3, no. 3 (1903): 144–61, doi:10.1111/j.1949-8594.1903.tb00704.x.

> essential that he should be started in the right way. Such fundamental work rests in the hands of the teachers in the high schools and colleges.[18]

In their zeal to revolutionize chemistry, physical chemists like Jones—and as we will see, Lash Miller and Kenrick—believed that reforming high school teaching was crucial. It was not simply a matter of introducing new content, but of implementing a new methodology. For Lash Miller, this meant reducing or even eliminating the role of the atomic theory and insisting on a quantitative, experimental approach to teaching chemistry.

THE TORONTO CHEMISTS' CAMPAIGN

Whether or not he had read Jones' words, Lash Miller clearly shared his conviction: physical chemistry was the chemistry of the future, and it called for a refashioning of chemistry education, especially the education of beginners. Lash Miller was deeply involved in the discipline's American expansion: at the invitation of Wilder Bancroft, whom he had met in Leipzig, he directed the review staff of the *Journal of Physical Chemistry* from its founding in 1896, and he joined the American Electrochemical Society, established in 1902, eventually serving as its president. Meanwhile, the University of Toronto's chemistry department, where Lash Miller gradually worked his way up from demonstrator to department head, maintained close ties to Ostwald's laboratory. During Lash Miller's tenure, the department became an enclave of physical chemists, partly due to its practice of hiring its own graduates, including Frank Kenrick and F. B. Allan.[19] Lash Miller also turned his energies toward reforming high school chemistry teaching. Most notably, he helped create a new curriculum and teachers' manual, *The New Requirements for Junior Matriculation in Chemistry*, which he distributed and promoted at the 1905 OEA meeting.[20] A year later, he followed with *Chemistry for Schools*,

18. "Symposium" (ref. 17), 158.

19. Kenrick, a Toronto alumnus, earned his PhD in Ostwald's laboratory in 1896, while Allan completed a PhD in physical chemistry under Lash Miller. Toronto also sent many graduates to Leipzig. Adrian G. Brook and W. A. E. Peter McBryde, *Historical Distillates: Chemistry at the University of Toronto Since 1843* (Toronto: Dundurn Group, 2007), 59 and 99.

20. William Lash Miller, *The New Requirements in Chemistry for Junior Matriculation and for the Departmental Examinations of the Province of Ontario* (Toronto: University of Toronto, 1905); "Minutes of the Natural Science Section," in *POEA* 44 (Toronto: William Briggs, 1905), 22–24. Passing the junior university matriculation examination allowed students to enter university;

edited in collaboration with Kenrick and Allan, which soon incurred George Cornish's remonstrations.[21]

Lash Miller and his colleagues presented their pedagogical approach as a modernizing move that captured an emerging spirit of reform among chemists. "In recent years a radical change has taken place in the methods of expressing and teaching the fundamental facts of chemistry," trumpeted the promotional pamphlet that publisher W. J. Gage sent to the Department of Education. This change consisted primarily of omitting the "unsatisfactory hypothetical element."[22] The textbook itself opened by invoking a sea-change in thinking about the atomic theory. "During the last decade an animated discussion has been carried on in the scientific literature as to the proper place of the atomic and molecular hypotheses in chemistry," began the editors in their preface. "The conviction is rapidly gaining ground that these hypotheses should be excluded altogether from the earlier stages of instruction." The book concluded by proclaiming a trend among chemists to abandon the atomic theory, which had outlasted its utility.[23] The change in pedagogy allegedly flowed from widespread doubts among chemists about the scientific merits of atomism.

As mentioned above, there *were* high-profile exchanges about atomism among prominent chemists and physicists. Ostwald had delivered his Faraday Lecture, in which he had announced the obviation of the atomic theory by energetics, just two years before the publication of *Chemistry for Schools*. But not many chemists followed Ostwald in repudiating atoms.[24] Even Lash Miller remarked in an early address to the OEA that "the Germans" had perhaps gone too far in their rejection of atoms.[25] This caveat notwithstanding, Lash Miller expressed vehement reservations about the atomic theory. He repeatedly challenged the atomic theory's fruitfulness and explanatory power, particularly regarding thermodynamics, and blamed it for retarding the progress of chemistry and obscuring chemists' terminology.[26] Until Jean Perrin's decisive

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however, students typically pursued junior matriculation as the first step toward a public school teaching certificate.

21. G. K. Mills, *Chemistry for Schools*, ed. William Lash Miller, Frank B. Kenrick, and F. B. Allan (Toronto: Gage, 1906).

22. W. J. Gage & Co. to A. H. U. Colquhoun, 18 Jun 1907, AO, RG 2-13, Box B271058, Folder 1907 Jun-Dec.

23. Mills, *Chemistry for Schools* (ref. 21), preface and 218.

24. Servos, *Physical Chemistry* (ref. 3), 69–70.

25. William Lash Miller, "Chemical and Physical Reactions," *POEA* 41 (1902): 200–206, on 205.

26. A 1907 meeting of the University of Toronto Chemical Society about the "Atomic Hypothesis," chaired by Lash Miller, sheds light on the Toronto chemists' reservations about the

experiments on Brownian motion in 1908, it was still plausible, if increasingly unusual, to doubt or deny the existence of physical atoms. Turn-of-the-century experimental work in physics, like J. J. Thomson's on the cathode ray and Ernest Rutherford's in radioactivity, strengthened the case for physical atomism, but it remained an instance of inference to the best explanation.[27] For Lash Miller (and Kenrick and Allan), the evidence for atomism was deficient, and the potential harmfulness of invoking atoms as an explanation outweighed its value as an aid to memory. Chemistry still lacked a grand unifying theory, he maintained: "The place which the theory of evolution holds in Biology, is, in Chemistry, still unfilled."[28]

Lash Miller's criticisms of the atomic theory's explanatory power pervade his pedagogical writing and reveal a deep suspicion of mechanistic accounts of nature. In his view, to reach for "explanations"—he nearly always put the word in scare quotes—was a natural psychological impulse, but a misguided one. "When striking and unfamiliar facts force themselves on the attention, there is a natural desire to 'explain' them in some way or other," he wrote in *The New Requirements*. This impulse had prompted people to invoke the atomic theory as an explanation for the laws of reciprocal and multiple proportions. Here, Lash Miller interposed one of his characteristic historical morality tales, painting the history of science as a model of Baconian induction and restraint. He speculated that the popularity of the atomic theory was the heritage of "the powerful impression produced on men's minds by the astronomical discoveries

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atomic theory. The minutes note that the atomic hypothesis successfully explained discontinuity in the composition of chemical compounds, Gay Lussac's law, van 't Hoff's laws, and recent discoveries in physics like Einstein's surface tension measurements and radioactivity. But it could *not* explain Faraday's law (of electrolysis), valency, nor the law of combination in simple multiple proportions. Nor could it account for "the quantitative relations existing between osmotic pressure, vapour tension, freezing point, [etc.], which were discovered without the atomic hypothesis." Further, it hindered efforts to improve chemical shorthand and electrochemical formulas. Finally, it could not keep up with the results of thermodynamics. In the assessment of the Chemical Society, the atomic theory was superfluous, inadequate, and detrimental. See "Atomic Hypothesis," 29 Mar 1907, University of Toronto Chemical Society Minutes, 1906–1909, University of Toronto Archives, University of Toronto Department of Chemistry, A1977-0025, Box 001, Folder 20, 49–52.

27. For the evidentiary status of physical atomism at the turn of the twentieth century, see Alan Chalmers, chapters 11–13 in *The Scientist's Atom and the Philosopher's Stone* (Dordrecht: Springer Netherlands, 2009), 215–60. For a contemporary assessment of the evidence, arguing for the reality of atoms, see A. W. Rücker, "Address of the President of the British Association for the Advancement of Science," *Science (New Series)* 14, no. 351 (19 Sep 1901): 425–43, doi:10.1126/science.14.351.425.

28. Lash Miller, *New Requirements* (ref. 20), 30.

of the seventeenth century." Leibnitz, Laplace, and Dalton had envisioned a mechanistic world filled with particles in motion. It had seemed inevitable that some "younger Newton" would come along and "reduce all science to the 'mechanics of the atoms'"—but this younger Newton had yet to appear. In the meantime,

> the waiting world has had time to reflect on [the] motto *hypotheses non fingo*, and to realize that from the days of Galileo none of the founders of mechanics and astronomy made their reputations by inventing "explanations" of the motions of the planets or the fall of apples, but by observing facts, describing them accurately and simply in mathematical language, and collecting the results of their work in the form of a few unexplained generalizations, or "laws."[29]

Lash Miller mocked what he saw as fanciful mechanistic images and rejected the notion that any such "mental pictures" were a legitimate form of explanation in science. The lesson on spurious explanations was laid out even more vividly for pupils in *Chemistry for Schools*. Imagine, the editors wrote that one evening we see in the distance a red glow on the horizon, which suggests the mental picture of a burning house. We might assume that this image has "explained" the facts. But such images are misleading: "On hearing next day that the same phenomenon had been observed all over the country, we give up our mental picture of the burning house and content ourselves by saying that we had seen a rather unusual type of the Aurora Borealis." Just as the burning house image might prevent people from studying the aurora, so the atomic theory had led to "the imperfect study or total neglect of certain classes of phenomena which did not fit in well with this explanation."[30]

Furthermore, the Toronto chemists repeatedly emphasized that hypotheses led to murky thinking and that drawing a stark separation between facts and hypotheses was "necessary to clear thinking."[31] Lash Miller's pedagogical arguments about the atomic theory stemmed in part from an inveterate insistence on precise, scrupulous thinking.[32] In his teacher's manual, he argued that

29. Ibid., 25.

30. Mills, *Chemistry for Schools* (ref. 21), 217–18.

31. Ibid., preface.

32. A fixation on clear thinking was evidently a basic part of Lash Miller's temperament, judging by how often it came up in obituaries and student reminiscences. "His inexorable principle which he applied with almost terrifying relentlessness was the insistence on the clear understanding and expression of fundamentals," wrote Kenrick in a 1941 obituary. Another obituarist described Lash Miller as "the enemy of loose and foggy thinking" who attacked ideas

invoking atoms to explain chemical formulas was a kind of hand waving: the teacher could only gesture to experimental work that lay far beyond pupils' comprehension and ask them to take it on faith. The teacher who eschewed atoms, by contrast, was forced to teach concepts from first principles. When pressed by a student about why H_2O is the formula for water, this latter teacher "must tell the whole truth or be found out. . . . He cannot dodge the issue, but must go into the whole matter again and again, until both he and his pupils are thoroughly familiar with the meaning of the chemical formulae, and of the laws on which their use is based."[33] *Chemistry for Schools* would make "greater demands on the thinking power of both pupil and teacher than would the more dogmatic method of hypothesis," the promotional pamphlet promised.[34] However, the consistency of the message about hypotheses in *Chemistry for Schools* was compromised by the uncritical introduction to ions in the final chapter on acids and bases. In this chapter, ions were described as "hypothetical" and "imaginary" substances, yet introduced as a simple way to understand and remember the properties of aqueous solutions of acids, salts, and bases.[35] Ions, unlike atoms, appeared to be admissible hypotheses.

This inconsistency notwithstanding, the Toronto chemists' cautionary statements about teaching hypotheses to beginners were a trope among contemporary science educators. As previously mentioned, nineteenth-century European chemists had used similar rhetoric about hypotheses. Johns Hopkins chemist and textbook author Ira Remsen likewise declared that atoms, as theoretical entities, were "not fit food for infant minds" (but conceded that a textbook that made no mention of the atomic theory "would never sell.")[36] Wesleyan University chemist Francis Gano Benedict argued that a first course in chemistry should not "confuse the mind with chemical theories" but merely introduce students to chemical phenomena. Theory, he claimed, was the first thing to be forgotten.[37] This wariness of theory extended beyond chemistry. Remsen, for example, maintained that theories—no matter how

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that "seemed to constitute . . . something less than demonstrated truth." Frank B. Kenrick, "William Lash Miller (1866–1940)," *Proceedings of the Royal Society of Canada* (1941), 131–34; Westman, "William Lash Miller" (ref. 5).

33. Lash Miller, *New Requirements* (ref. 20), 31.

34. Gage & Co. to Colquhoun, 18 Jun 1907, AO (ref. 22).

35. Mills, *Chemistry for Schools* (ref. 21), 213.

36. L. C. Newell, "Professor Remsen on the Teaching of Science," *SSM* 2, no. 3 (May 1902), 129–32, on 132, doi:10.1111/j.1949-8594.1902.tb00417.x.

37. Francis Gano Benedict, "The Teaching of Chemistry in Graded and Secondary Schools," *Science* (New Series) 18, no. 458 (Oct 9, 1903): 465–70.

well established—had no place in an elementary physics course, either.[38] In their 1904 manual for botany and zoology teachers, Francis Lloyd and Maurice Bigelow advised that the theory of evolution merited only "the briefest sketch" in a high school course, not because it was unsubstantiated or controversial, but rather because it involved "highly theoretical problems which are certain to be confusing to young minds."[39] Evolution was likewise only a marginal feature of the general biology curriculum before 1925, mainly because the course was intended to be observational and experimental.[40] Where theory did appear, educators insisted that facts and hypotheses be sharply distinguished, so as to avoid confusion and teach clear thinking.[41] In their stated eschewal of hypotheses, the Toronto chemists were following an established trend.

What made *Chemistry for Schools* stand out, then, were not its admonitions about hypotheses, but rather its blunt denunciations of the atomic theory and its manifestly contrarian tone. The beginner chemistry textbooks of the day were varied in their treatments of atomism. Alexander Smith, surveying American chemistry textbooks in 1902, noted three main methods of organization: the "nature study method," best suited to younger pupils in their first year of high school, which focused on simple, familiar substances and avoided topics like atoms and valency altogether; the "theoretical method," which emphasized the quantitative nature of chemical change and prioritized the study of gases so as to introduce theory—especially Avogadro's hypothesis—as quickly as possible; and the "historico-systematic method," which proceeded through successive chapters on different elements, interspersing theory along the way. The general tendency in the United States, Smith noted, was toward theoretical and historico-systematic approaches (though he himself expressed misgivings about these methods).[42] Educators' cautionary statements about hypotheses clearly did not translate into outright exclusion of the atomic theory. To consider one prominent example, Remsen's widely used *Introduction to the*

38. Newell, "Professor Remsen" (ref. 36), 132.

39. Francis E. Lloyd and Maurice A. Bigelow, *The Teaching of Biology in the Secondary School* (New York: Longmans, 1907), 138 and 287.

40. Philip J. Pauly, "The Development of High School Biology: New York City, 1900–1925," *Isis* 82, no. 4 (1991): 662–88, on 685–87.

41. Arthur S. Dewing, "Science Teaching in Schools," *SSM* 9, no. 1 (Jan 1909): 8–11, on 9, doi:10.1111/j.1949-8594.1909.tb01349.x.

42. Alexander Smith and Edwin H. Hall, *The Teaching of Chemistry and Physics in the Secondary School* (New York: Longmans & Green, 1902), 52–60.

Study of Chemistry (which Smith labeled "historico-systematic") stated its intent to keep theoretical "speculations" subordinate to the systematic study of phenomena. A common mistake, wrote Remsen in the preface, was to "[present] the profoundest theories of the science before the student is prepared for them." But unlike Lash Miller, Remsen freely used the language of atoms and molecules. He introduced the atomic theory in the fifth chapter, on the laws of chemical combination, as the simplest, though unprovable, account for the laws of definite and multiple proportions.[43] Meanwhile in Ontario, the one authorized textbook expressed no caution about theory. It introduced atoms on page 15, well before any discussion of equivalents or the laws of chemical combination. Moreover, it expounded a matter-of-fact *physical* atomism. "It is reasonably certain," it stated, "that all matter . . . is made up of separated particles, very minute, indivisible by physical means. . . . Such particles are called *molecules*. . . . The portions of matter that go to form a molecule are called *atoms*."[44] This "dogmatic" approach was exactly what Lash Miller sought to avoid.

TEACHING CHEMISTRY WITHOUT ATOMS

The method used in *Chemistry for Schools* to teach the laws of chemical combination without atoms was peculiar in its details, but its basic structure was neither new nor unique. Chapter 11 introduces the "law of reacting weights" (reciprocal proportions) using the formation of water as a case study, as was common. It states that the reacting weight of oxygen was "arbitrarily set" at 16 grams and then uses this weight to calculate reacting weights (equivalent weights) of hydrogen and water. The chapter then shows how reacting weights of other substances can be calculated from other reactions involving 16 grams of oxygen. "These are all obtained," the text emphasizes, "from the results of actual experiments." Finally, it shows how formulas can be derived from reacting weights and explains how, for the sake of uniformity and simplicity, standard reacting weights were selected for gases using Gay-Lussac's law. For other (non-gaseous) reacting weights, the text tersely notes that the selection of standard weights was informed by a variety of considerations that are

43. Ira Remsen, *Introduction to the Study of Chemistry*, 6th ed. (New York: Henry Holt, 1902), vi and 80–87.

44. A. P. Knight and W. S. Ellis, *High School Chemistry* (Toronto: Copp, Clark, 1895), 14–15.

"unsatisfactory" and beyond the purview of an elementary textbook: "All that concerns us . . . is that the choice has been made and is accepted by all chemists."[45]

In some ways, *Chemistry for Schools* fell in line with pedagogical conventions of the day. The editors' aversion to the atomic theory dovetailed conveniently with the inductive method in science teaching. The imperative of an inductive order leading from experimental facts to generalizations was nearly undisputed.[46] Both the *New Requirements* and *Chemistry for Schools* introduced the laws of chemical combination according to a pattern that had been canonized in nineteenth-century French chemistry textbooks and was recommended in American teachers' manuals well into the twentieth century.[47] The pattern of this inductive strategy was to begin by teaching the empirical laws of chemical combination—conservation of mass, definite, reciprocal, and multiple proportions—illustrating their experimental derivation with simple laboratory experiments. The next step was to introduce chemical equivalents, symbols, and formulas. Finally, Avogadro's hypothesis and the atomic theory could be introduced as a theoretical interpretation of these empirical laws. However, this order of presentation made it possible to omit the atomic theory entirely. In his 1902 teachers' manual, Alexander Smith acknowledged this pedagogical fork in the road: after presenting the laws of combination, the teacher could, "if he sees fit," present the atomic theory, Avogadro's hypothesis, molecular weights, and valency. But, he added, "many teachers do not favour a *complete* discussion of these subjects in the secondary school."[48]

In other ways, *Chemistry for Schools* was decidedly unorthodox. In addition to the book's distinctive appendix, the editors' unconventional nomenclature,

45. Mills, *Chemistry for Schools* (ref. 21), 118–25.

46. Rudolph, "Epistemology" (ref. 7), 352.

47. Kounelis, "Atomism in France" (ref. 42), 214–15; Smith and Hall, *Teaching of Chemistry and Physics* (ref. 2), 69–77; George Ransom Twiss, *A Textbook in the Principles of Science Teaching* (New York: Macmillan, 1917), 353–79.

48. Smith and Hall, *Teaching of Chemistry and Physics* (ref. 42), 76. As Alan Rocke has shown, there is a pronounced irony underlying such demarcations between the empirical and the theoretical. Any notion of a chemical equivalent (or what *Chemistry for Schools* called a "reacting weight") that assigned a characteristic, invariant weight to each element was necessarily theory-laden. Equivalents were therefore operationally equivalent to invoking atoms. See Alan J. Rocke, "Atoms and Equivalents: The Early Development of the Chemical Atomic Theory," *Historical Studies in the Physical Sciences* 9 (1978), 225–63; Rocke, *Chemical Atomism* (ref. 2).

which Cornish would later attack as idiosyncratic and outlandish, reveals many axes to grind.[49] Even its references to the atomic "hypothesis" were atypical and therefore pointed.[50] Naturally, the book eschews the terms "atomic weight" and "molecular weight." While noting that these terms are used by "many textbooks on chemistry," it uses "reacting weight" and "formula weight" instead.[51] The book quibbles with common uses of the word "reaction" as a synonym for change.[52] It notes that a solution of two liquids was often referred to as a "mixture," adding that "this practice is a bad one, and will not be adopted in this book."[53] It rejects common definitions of mechanical mixtures as "meaningless."[54] It remarks that while conservation of mass was commonly referred to as a "law," it "might much better be called a 'probability.'"[55] But the book's most conspicuous, extraordinary move is its use of the term "chemical individual," which allowed the editors to introduce what they regarded as a crucial demarcation between chemical individuals (marked by their constant composition, like water or salt) and solutions (whose composition could be gradually varied, like brine).[56] The textbook's careful distinction between mechanical mixtures, solutions, and chemical individuals bears the

49. Pointed language choices had also been a mark of *The New Requirements*. Lash Miller stressed, following Ostwald, that the term "conservation of matter" should be avoided, "as 'matter' is a metaphysical conception." Likewise, he proposed the term "international weights" over "atomic weights." Lash Miller, *New Requirements* (ref. 20), 6 and 28 n. 2. Organic chemist William A. Noyes, reviewing the book, judged Lash Miller's avoidance of the atomic theory to be extreme and excessive; *Journal of the American Chemical Society* 27, no. 3 (March 1, 1905): 319–20, doi:10.1021/ja01981a026.

50. A Google Ngram search suggests that the phrase "atomic theory" was used seven times more frequently than "atomic hypothesis" in print sources in 1907. Although the terms "theory" and "hypothesis" were sometimes used interchangeably among educators, "hypothesis" generally implied (as it does today) a more speculative, as-yet-untested proposition. See, for example, Remsen, *Introduction* (ref. 43), 80–81.

51. Mills, *Chemistry for Schools* (ref. 21), 129. These were also unusual substitutions: conventional alternatives were "equivalent weight" or "combining weight."

52. Ibid., 12.

53. Ibid., 82.

54. Ibid., 114.

55. Ibid., 47. Even the book's nomenclature for ions (hydrogenion, hydroxidion, chloridion) was unusual, as most chemists had adopted physical chemist James Walker's nomenclature; see A. S., review of *An Elementary Laboratory Course in Chemistry*, by Frank B. Kenrick and Ralph E. De Lury, *Journal of the American Chemical Society* 28 (Aug 1906): 1084–86.

56. Mills, *Chemistry for Schools* (ref. 21), 72–73. This demarcation laid the groundwork for the law of reacting weights, which, the writers stressed, applied only to reactions involving chemical individuals; see 118–23.

clear influence of Ostwald, who had elaborated this distinction in his 1904 Faraday Lecture.[57]

The model of beginners' chemistry developed by Lash Miller, Kenrick, and Allan was a model that rejected standard vocabulary and conventional definitions in favor of terms that expressed their experimental origins. This purity of expression, they believed, would groom students in clear thinking, experimentalist discipline, and the importance of sticking to "facts." Such habits evidently outweighed the benefits of shared access to a common, international discourse of chemistry. Significantly, their model also laid the groundwork for future studies at the University of Toronto, where the quantitative methods of physical chemistry were paramount. Unfortunately, their priorities were largely out of step with the perceived mission of high school science teaching and with the changing principles of beginners' pedagogy at the turn of the twentieth century. Their claim to representing a majority view on atomism was dubious. Cornish attacked the Toronto chemists on all these fronts. What was at stake was not merely the contents of the curriculum, but also the purpose of high school chemistry teaching and the professional authority of its teachers.

THE CASE FOR TEACHING THE ATOMIC THEORY IN HIGH SCHOOLS

In March 1907, roughly two weeks before the annual OEA meeting, the University of Toronto Chemical Society, an informal club consisting mostly of faculty members, noted that Cornish was slated to give an address about the atomic theory and sent a letter inviting him to their next meeting. It would be chaired by Lash Miller, and the evening's topic was "the use of the atomic theory in elementary instruction in chemistry." Cornish tersely but politely declined, writing that he preferred to save his remarks for the upcoming OEA meeting. His refusal ensured that the discussion would take place not among university chemists, but at a meeting of the province's science teachers. "I will take a stand not in complete accord with the views of Drs. Miller and Kendrick [*sic*]," he warned.[58]

57. Wilhelm Ostwald, "Faraday Lecture: Elements and Compounds," *Journal of the Chemical Society, Transactions* 85 (1904): 506–22, doi:10.1039/CT9048500506.

58. G. A. Cornish to J. A. Dawson, 27 Mar 1907 (misdated 1906), in University of Toronto Chemical Society Minutes 1906–1909, University of Toronto Department of Chemistry (ref. 26).

His address was considerably more combative than he had hinted. Cornish took the Toronto chemists' low regard for high school chemistry teaching as an insult to Ontario high school teachers. Delivering his address in a University of Toronto lecture hall, Cornish confronted the Toronto chemists on their own turf. "According to the testimony of these chemists," he said, "the students who come to them have their minds stuffed with atoms and molecules, and know little chemistry, and, from the lecturer's desk, they even suggest to the students that they forget all the chemistry they were taught in high school. . . . This is a serious indictment against the science teachers of the province. . . . I do not believe that such an attitude on the part of university men is at all merited."[59] Cornish repeated a refrain that had become commonplace among high school educators not only in Ontario, but across the United States and Canada: the main purpose of a high school education was not to prepare a select group of students for university, but rather to provide a general education.[60] The high school curriculum, in other words, should not be bent to the priorities of university professors.

Cornish's emphasis on life preparation and general education entailed a fundamentally different conception of beginners' pedagogy. This view prioritized students' induction into an established, conventional scientific discourse. For Cornish, the objective of an elementary education in chemistry was—granting the anachronism—a basic scientific literacy. "The public demand that the student [who has studied chemistry in high school] shall have a working knowledge of the subject, . . . and shall have such a knowledge of the terms and methods of thought in chemistry that he can read intelligently an ordinary book on the subject or a magazine on the same," he claimed. This objective did not allow for the contrarian language in the new textbook: "I claim that with such a course as that outlined in Mills' Chemistry for Schools . . . , [the student] would be entirely at sea on reading any extended book on chemistry." The editors had felt compelled to "banish all the terms that have become the vocabulary of chemistry in the last fifty years," Cornish alleged, pointing to idiosyncratic terms like "chemical individual," "reacting weight," and "formula weight."[61]

59. Cornish, "Atomic and Molecular Theories" (ref. 1), 198.

60. See, for example, W. S. Ellis, "The Making of a Curriculum," *Canada Educational Monthly* 26 (1903): 296–300; "Report of the Proceedings of the Chemistry Section of the C. a. S. & M. T. at Its Fourth Meeting," *SSM* 5, no. 2 (Feb 1905): 120–26, doi:10.1111/j.1949-8594.1905.tb04473.x.

61. Cornish, "Atomic and Molecular Theories" (ref. 1), 203.

Cornish strenuously defended teaching the atomic theory in high schools. Like the Toronto chemists, Cornish invoked the inductive method, but a version of induction that *relied on theory* as its capstone. For Cornish, the hypothetical nature of the atomic theory did not warrant its exclusion from the curriculum. The use of atomic theory in Ontario schools was "grossly abused," he conceded, but only because it ignored the inductive method. (In the current textbook, the atomic theory was presented at the beginning of the course, rather than as the culmination of prior experimental work.[62]) But this problem was easily remedied by restoring the atomic theory to its rightful place as the culmination of the inductive order, where it unified and correlated the concept of chemical equivalent and the laws of definite, multiple, and reciprocal proportions. "Without the atomic theory these facts are isolated and unrelated generalizations. Let the theory of atoms be assumed and at once a new light is shed upon them, and they all take their place in a single picture, and will be remembered and understood much more perfectly by the young mind, because the immature mind is fond of the concrete," he declared. Atoms, though hypothetical entities, rhetorically became the "concrete" image that unified the curriculum.

Cornish not only challenged the Toronto chemists' vision of beginners' pedagogy, but also contested their claims about the scientific and heuristic value of hypotheses. Sidestepping any debate about the evidence for physical atoms, Cornish argued that the atomic theory was useful *even if it was not true*. He quoted at length from physicist Arthur Rücker's 1901 address to the British Association for the Advancement of Science: "From the practical point of view, it is a matter of secondary importance whether our theories and assumptions are correct, as long as they guide us to results which are in accord with the facts."[63] Moreover, hypotheses were essential in science teaching: "Nobody teaches astronomy or geography without the use of La Place's nebular theory and the heliocentric theory of the solar system. Theories of evolution are essential in biology and the facts of physics are incomprehensible without the molecular theory, and the theory of the ether." Why banish the atomic theory

62. Knight and Ellis, High School Chemistry (ref. 44), 13–17.

63. This address became widely available to teachers when it was republished (in abridged form) in *School Science and Mathematics*. Ironically, Rücker had cited this instrumental interpretation of hypotheses in order to denounce it. A philosophy of science that regarded matter as fundamentally unknowable was inadequate. The weight of evidence demonstrated that atoms were not mere convenient fictions but real physical entities. A. W. Rücker, "The Construction of a Model of Nature and the Limits of Physical Theories," *SSM* 1, no. 5 (1901): 236.

when hypotheses were indispensable in all other branches of science?, Cornish demanded.

Cornish's most forceful allegation, however, was that the University of Toronto chemists were an isolated faction, out of touch with consensus views. Here, Cornish revealed the lengths of his counter-campaign against the Toronto chemists' curriculum reform. "I have searched diligently for some sign of this tendency to abolish the atomic theory from the teaching of chemistry," he stated. He reported that he had pored over "several dozen" recent textbooks. These were not high school textbooks, it should be noted, but rather introductory college-level textbooks. Citing textbook authors both American (Ira Remsen, Harry C. Jones, Alexander Smith) and British (George Samuel Newth), as well as legendary greats like Mendeleev (whose *Principles of Chemistry* he quoted at length), Cornish claimed that all their elementary textbooks "[used] the theory freely" or, like Mendeleev, explicitly defended the role of hypothesis in science. Even Ostwald, he noted pointedly, endorsed the use of the atomic theory as a convenience in his *Conversations on Chemistry*. He went on to disclose that he had sent a copy of Ontario's new chemistry curriculum to William Ramsay and James Dewar ("not merely chemists, but also educationists of a very high type"), both of whom had written back to express their unequivocal belief that the atomic theory should not be excluded from an elementary course. Dewar's reply gave Cornish particularly excellent ammunition: "I don't think you can possibly teach anything useful in chemistry without introducing the atomic and molecular theories," Dewar had written. "Surely the omission is pure inadvertence. An 'engineer' trained with no reference to theory is called an artisan, and is a poor one at that. Does the department wish you to turn out analytical operators? Such a course as you suggest might suit for an analyst who was required to estimate iron in iron ore and nothing else—in fact, a chemical laborer. But you state that . . . the syllabus is intended to form part of a general education." Finally, Cornish had consulted courses of study in Britain, France, Germany, "all the British Colonies," and the United States. "The atomic and molecular theories are introduced in courses that are not nearly as extensive as is ours in Ontario," he reported. He declared in closing that the university chemists, in their "crusade" to reform chemistry teaching, had gone too far. Despite his extensive research, Cornish claimed that he could find no support for abolishing the atomic and molecular theories: "I do not believe that radical changes of such a nature should be introduced until supported by the majority of chemists," he concluded.

The minutes give no indication of how Lash Miller, who was in the audience, replied to these charges, nor how the assembled teachers responded, beyond a spirited discussion and a vote to publish Cornish's address in the proceedings. However, the minutes do note that the meeting adjourned to the University of Toronto's Chemistry Building to hear Ernest Rutherford deliver a lecture on the transformation of matter. In a few months, Rutherford would move to Manchester, but in April 1907, he held an appointment at McGill University in Montreal, where he carried out much of the research on radioactivity that would earn him the Nobel Prize in 1908. The juxtaposition of the OEA debate about the atomic theory and this lecture by Rutherford, whose research lent such powerful support to atomism, illustrates, with the benefit of hindsight, just how unique circumstances were for disputes about the heuristic value of the atomic "hypothesis." Atomism was steadily gaining ground, and by 1909, it was no longer plausible to deny the physical reality of atoms. If atoms and molecules were not hypothetical entities, then they could no longer be excluded on these grounds. But both sides of the debate had made their case in ways that carefully avoided narrow questions of evidence. Instead, the dispute was fueled on rhetoric about what an inductive method entailed, what best exercised the reasoning powers of beginners, what best secured their learning, what the purpose of an elementary science education ought to be, and whether new terminology brought clarity or confusion. It raised questions about who had jurisdiction over the high school curriculum and who could justifiably claim to represent a majority view on elementary chemistry teaching. Because the debate cast such a wide net, it could not be settled by a simple assessment of evidence.

DEBATING ATOMISM ABROAD: DISSENSION AMONG AMERICAN EDUCATORS

If Lash Miller had overstated his case about a trend among chemists toward abandoning the atomic theory, Cornish had also exaggerated the counter-case. There was no easy consensus about the place of the atomic theory in elementary chemistry teaching. The Cornish–Lash Miller exchange was not just a tempest in a teapot: the atomic theory had become a flash point for debate among American educators as well, a topic that was raised repeatedly by contributors to *School Science and Mathematics*.[64] Most prominently, just two

64. See, for example, Newell, "Professor Remsen" (ref. 36); John Waddell, "The Formula of Water," *SSM* 5, no. 3 (Mar 1905): 192–95, doi:10.1111/j.1949-8594.1905.tb04491.x; Milo S. Baker,

months before the OEA meeting, in the February 1907 issue, University of Chicago chemist Alexander Smith had published an extended attack on what he saw as the misuse of the atomic theory in beginner courses. (*School Science*, founded in Chicago in 1901, had been marketed by its editors at OEA meetings, and it is plausible that Cornish or some members of his audience had read Smith's piece.) In a short series of articles that parallels the Ontario debate in striking ways, Kansas City high school teacher Fredus Peters faced off against Smith, challenging Smith's expertise in beginners' learning and defending the teaching of the atomic theory.[65] Unlike Lash Miller, Smith did not express skepticism about the atomic theory. Rather, he argued that beginner textbooks wrongly treated the atomic theory as though it were the fundamental principle of chemistry, a status that in his view it emphatically did not deserve.

Alexander Smith, like Lash Miller, was a physical chemist, and an evangelistic one. In 1906, he had published an influential college textbook, *Introduction to General Inorganic Chemistry*, likely one of the textbooks Cornish referenced in his OEA address.[66] He was also an authority in high school pedagogy, having co-authored, along with Harvard physicist Edwin Hall, the 1902 teachers' manual *The Teaching of Chemistry and Physics in the Secondary School*. Although Cornish had cited Smith as an ally (Smith's textbook did teach atomic weights), Smith's repeated calls for empiricism and careful quantitative analysis, as well as his concerns about the overuse of the atomic theory in high school teaching, were closely aligned with Lash Miller's.[67] In his 1902

"How Much Chemical Theory Shall Be Taught in the High School and How Shall It Be Presented?" *SSM* 6, no. 4 (Apr 1906): 273–83, doi:10.1111/j.1949-8594.1906.tb00966.x; Roy Fryer, "Chemical Theory in the High School Course," *SSM* 6, nos. 8 and 9 (Nov and Dec 1906): 688–91 and 730–735, doi:10.1111/j.1949-8594.1906.tb02924.x and 10.1111/j.1949-8594.1906.tb02942.x; and Wm. Lloyd Evans, "The Position of Atomic Theory," *SSM* 7, no. 7 (Oct 1907): 547–56. doi:10.1111/j.1949-8594.1907.tb01073.x.

65. Alexander Smith, "The Point of View in Chemistry," *SSM* 7, no. 2 (Feb 1907): 128–35, doi:10.1111/j.1949-8594.1907.tb03006.x; Fredus N. Peters, "Another Point of View in Chemistry," *SSM* 7, no. 6 (Jun 1907): 502–7, doi:10.1111/j.1949-8594.1907.tb17559.x; Alexander Smith, "Comment on 'Another Point of View'," *SSM* 7, no. 6 (Jun 1907): 508–10, doi:10.1111/j.1949-8594.1907.tb17560.x. See also Fredus N. Peters, "What and How Much in High School Chemistry," *SSM* 8, no. 2 (Feb 1908): 107–15, doi:10.1111/j.1949-8594.1908.tb01100.x; Alexander Smith, "The Experimental Viewpoint in Chemistry," *SSM* 8, no. 7 (Oct 1908): 582–90, doi:10.1111/j.1949-8594.1908.tb01266.x.

66. Alexander Smith, *Introduction to General Inorganic Chemistry* (New York: The Century Co., 1906).

67. Smith had moved away from his training as an organic chemist to enthusiastically embrace and promote quantitative physical chemistry. See Donald Cotter, "A Disciplinary Immigrant:

manual, he had argued forcefully that the atomic theory skewed beginners' perception of chemistry. For Smith, the task of a beginner's course was to convey an "accurate" image of chemistry: an elementary course should be a faithful, miniaturized microcosm of the discipline as a whole. The teacher's—and the textbook author's—crucial task was to keep all parts in their correct proportions: "The elementary course in chemistry should represent the main features of the science *in petto*, and show it, as it were, viewed through the wrong end of an opera-glass."[68]

Smith reiterated this argument about accurate representation in his 1907 *School Science* piece. He argued that designing a chemistry course involved careful selection, not of topics to be covered, but of a "point of view," a metaphorical vantage point within the landscape of chemistry. Studying science was like exploring a large territory, he wrote. At best, the teacher could bring students on "short excursions" to some viewpoint. There, the teacher was compelled to stop and describe the terrain in the distance, because students lacked the time and ability to explore it themselves. Smith lamented that atoms were too often given undue pride of place in this vast and varied landscape:

> Now, obviously, to give a true conception of the whole, the viewpoint must be chosen with some care.... Some of us, feeling confident that our viewpoint has been chosen with exceptional success, set up a camera, take a snapshot of the subject, and circulate the prints under the name of So and So's Complete Chemistry.... We teachers, who have seen the science from other sides, may have considerable difficulty in explaining the picture so as to restore to their true proportions objects near to and far from the viewpoint. How unfortunate, for example, it is that the camera is so often planted right behind a molecule! What a heavy task this lays upon the teacher who has to reduce the all too obvious atoms to their true place and proportions![69]

Smith's metaphor, which construed chemistry as a territory, students as explorers, and the teacher as the guide, made the textbook, by implication, the guidebook—an image strikingly consonant with Thomas Kuhn's later comparison of textbooks to tourist brochures.[70] Smith claimed that he was not disputing the "truth" of atom-centric textbooks ("There *are* atoms and

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Alexander Smith at the University of Chicago, 1894–1911," *Annals of Science* 65, no. 2 (Apr 2008): 221–56, doi:10.1080/00033790701576206.

68. Smith and Hall, *Teaching of Chemistry and Physics* (ref. 42), 161.

69. Smith, "Point of View" (ref. 65), 131.

70. Thomas S. Kuhn, *The Structure of Scientific Revolutions*, 3 rd ed. (Chicago: University of Chicago Press, 1996), 1.

molecules in chemistry," he wrote), but rather their distorted perspective. Their images were the work of "amateur photographers" who had not consulted the work of "professionals" and whose photographs "should go to the editor of the 'freak photograph' section of one of the magazines, rather than into the hands of beginners of chemistry." Chemistry teaching, Smith claimed, should be based on observation and "plain, literal, experimental terms." Hypotheses had only a very limited utility: to explain and relate facts. Whenever possible, they should be discarded, like the scaffolding of a building.

In his reply, Fredus Peters took aim at Smith's claims about beginners.[71] A major point of disagreement between Smith and Peters was the pedagogical merit of equivalent weights (what Lash Miller called "reacting weights"), a purportedly empirical way to teach the laws of chemical combination without resorting to atomic weights.[72] Here again, the debate centered on what was best suited to beginners' minds. For Smith, equivalent weights, which relied on literal language of experiment rather than difficult-to-interpret language of hypothesis, would give "the least trouble to the halting mental activity of the beginner."[73] Peters retorted that equivalents were "hopelessly abstract" to the beginner. A scholar could reason in the abstract, but a student needed concrete terms. Like Cornish, Peters argued that atoms were the *concrete* image that students needed. Part of the problem, Peters implied, was that Smith, a college professor, was out of touch with beginners' needs: "[Dr. Smith] deals with the mature student, I with the beginner," he wrote. Smith published a short response, insisting that a formula explained in terms of atoms was "vastly more abstract" than a formula understood as relative weights.[74]

These repeated appeals to beginners' minds in discussions about the atomic theory reveal the shifting dynamics of American public education at the turn of the century. In colleges of education, a new class of professional educators was challenging the authority of subject-matter specialists like Smith. Psychologists such as Edward Thorndike, G. Stanley Hall, and John Dewey looked to education to both apply and legitimize research in experimental psychology.[75] Smith's subject-centered approach, focusing as it did on the "accurate"

71. Peters, "Another Point of View" (ref. 65), 503.

72. See commentary and sources in ref. 48.

73. Smith, "Point of View" (ref. 65), 131.

74. Smith, "Comment" (ref. 65).

75. Ellen Condliffe Lagemann, chapters 1 and 2 in *An Elusive Science* (Chicago: University of Chicago Press, 2002), 1–71; Diane Ravitch, *Left Back: A Century of Battles Over School Reform* (New York: Simon and Schuster, 2001), 52–57.

representation of chemistry, was falling out of favor. Attention had turned instead to children's mental development, individual abilities, and natural interests. Reform-minded science educators, drawing particularly on G. Stanley Hall's child study movement, argued that requiring students to perform a succession of quantitative laboratory experiments—the pedagogy Smith so staunchly defended—was dry and out of step with students' interests.[76] Reformers claimed that a one-size-fits-all academic curriculum was unsuitable for the vast majority of high school students and, crucially, was not *useful* to their everyday lives or their future occupations.[77] These arguments also shaped educators' discussions about teaching theory. At a 1904 meeting of science teachers in Chicago, for example, one participant argued that the theory-laden, university-oriented approach to teaching chemistry in high schools was repelling students and driving down enrollments.[78] Another high school teacher writing in *School Science* argued that high schools should teach just enough theory that the college-bound student would have a basis, while others would not waste time on topics for which they "would probably find no future use."[79] Just as William Ramsay had claimed that a theoretical education distinguished the true chemist from the "chemical laborer," the atomic theory, in the context of the early twentieth-century push for differentiated education, became a marker of ability, ambition, and social class, demarcating the academic, college-oriented curriculum from the practical curriculum for the average student.

RESOLVING THE ONTARIO TEXTBOOK QUESTION

Were these debates about the pedagogical merits of teaching the atomic theory carried into the mechanisms of textbook selection? In Ontario, the adjudication process, carried out by a government-appointed committee, was insulated from these debates. When, in 1907, the Minister of Education initiated a review

76. John Rudolph describes, for example, Charles Ryborg Mann's attack on physicist Edwin Hall's influential "Harvard list" of physics experiments in "Epistemology" (ref. 7), 359–61. See also Kathryn M. Olesko, "German Models, American Ways: The 'New Movement' Among American Physics Teachers, 1905–1909," in *German Influences on Education in the United States to 1917*, ed. Henry Geitz, Jürgen Heideking, and Jurgen Herbst (Cambridge: Cambridge University Press, 2006), 129–53.

77. Herbert M. Kliebard, *The Struggle for the American Curriculum, 1893–1958*, 3 rd ed. (New York: RoutledgeFalmer, 2004), 36–44; Ravitch, *Left Back* (ref. 75), 69–87.

78. "Chemistry Section" (ref. 60), 130.

79. Fryer, "Chemical Theory" (ref. 64), 735 (my emphasis).

of the province's high school textbooks, *Chemistry for Schools* was considered, but ultimately not selected for authorization. The committee charged with reviewing science textbooks paused over *Chemistry for Schools*' treatment of the atomic theory: "It ignores the atomic theory as a means of explaining the facts of chemistry," they wrote. "This may not be a defect, but the relegation of this theory to a page at the end is very unusual for an elementary text-book." But the reviewers' hesitation on this point was just one item in a list of demerits, and they were evidently more concerned about other flaws. Directives in experiments were too vague, they wrote, and the book did not provide a systematic introduction to inorganic chemistry. The book was better suited to students who would enter the university than to aspiring public school teachers. Moreover, it was "rather dull and uninteresting for pupils." Finally, the committee noted the inferior quality of the book's paper.[80]

The controversy over the atomic theory was thus sidelined by other pedagogical priorities. Deliberations over the chemistry textbook dragged into the next two years. Finally, in 1909, the Education Department paid a committee of four Ontario science teachers to rewrite the authorized textbook.[81] In doing so, it brought the process closer to the concerns of the OEA. The teachers tasked with the revision were members of the Natural Sciences section of the OEA, and at least three had been present at Cornish's address in 1907.[82] Their new textbook and its accompanying laboratory manual were published anonymously in 1909.[83] Although OEA members knew the identity of the authors, students were presented with a textbook whose title page carried only the authoritative stamp of the Minister of Education. The fraught interpersonal discussions over pedagogy were subsumed into the bureaucratic edict of the Department of Education.

The new textbook, however, bore the marks of the atomic theory controversies. In most ways, it followed Cornish's exhortations. It devoted a chapter to the atomic theory and another to atomic weights, and these chapters came

80. Gage & Co. to Golquhoun, 18 Jun 1907, AO (ref. 22). This last comment points to Ontario's fraught politics of textbook pricing and quality, which had been the impetus for a sweeping government-initiated investigation of textbook production in 1906–1907. See Penney Clark, "'Reckless Extravagance and Utter Incompetence': George Ross and the Toronto Textbook Ring, 1883–1907," *Papers of the Bibliographical Society of Canada* 45, no. 2 (2008): 185–236.

81. Memorandum for the Provincial Auditor, 30 Nov 1909, AO, RG 2-13, Box B271059, Folder 1909.

82. The authors identified themselves at the 1910 OEA meeting. "Minutes of the Natural Science Section" in *POEA* 49 (Toronto: William Briggs, 1910).

83. *Ontario High School Chemistry* (Toronto: Macmillan, 1909).

later than the chapter on the law of definite proportions, per the standard inductive order. In one aside that reads as a concession to Lash Miller, the authors state that "[the] use of the term atom does not, in any way, serve as an *explanation* of the chemical facts [of the Law of Multiple Proportions]; it is simply a ready way of expressing a theory regarding them." In addition, "atom" is defined operationally as "the unit mass of an element that takes part in chemical reactions"—a definition that invoked a noncontroversial chemical atomism rather than a still-contentious physical atomism. The text elaborates: "[The] smallest mass of water consists of two unit masses of hydrogen united with one of oxygen. Notice, it is not said two *particles* of hydrogen and one of oxygen, but two *units of mass*." Nevertheless, the authors defended their use of the term "atoms" over "combining weights," stating simply that this nomenclature was "more desirable on the whole."[84]

Both Lash Miller and Kenrick continued to criticize high school chemistry teaching in the years following the authorization of the anonymous 1909 textbook, but intermittently and to little effect.[85] Kenrick, clearly unhappy with the new textbook, presented a list of its "inaccuracies and inconsistencies" at the 1914 OEA meeting. An OEA committee was appointed to take it up with the Minister, but was told that the Department was disinclined to make changes.[86] By this time, the disruptions of the First World War had diverted Lash Miller's attentions. When the chair of the Chemistry Department volunteered for service, Lash Miller became the de facto chair, and even his research was suspended as the war effort took over the University of Toronto campus.[87] The 1909 textbook remained the sole authorized chemistry textbook for Ontario high schools until 1917.

TEACHING THE ATOMIC THEORY AFTER PERRIN

In 1908, as the fate of Ontario's high school chemistry textbook hung in limbo, Jean Perrin was performing a series of experiments on Brownian motion that would be greeted as definitive evidence for the physical reality of atoms.

84. Ibid., 53–54 (my emphasis).

85. See, for example, Lash Miller, "The Chemical Philosophy of the High-School Text-Books," *Science* 34, no. 870 (1911): 257–63.

86. "Minutes of the Natural Science Section," *POEA* 53 and 54 (Toronto: William Briggs, 1914 and 1915).

87. Brook and McBryde, *Historical Distillates* (ref. 19), 77–79.

Perrin's results famously prompted Ostwald's own conversion. In the preface of the 1909 edition of *Grundriss der allgemeinen Chemie*, Ostwald described the atomic hypothesis as "a scientifically well-grounded theory" that "can claim a place in a textbook intended for use as an introduction to the present state of our knowledge in general chemistry."[88] By this point, however, debates about teaching the atomic theory in Ontario and American secondary schools had long been framed in pedagogical discourse that had little contact with questions of evidence.

The Toronto chemists failed to erase all reference to atoms and molecules from Ontario's official high school chemistry textbook. However, they evidently succeeded in convincing some teachers that the atomic theory was superfluous for teaching chemistry. Toronto chemistry teacher Carl Lehmann, for example, propounded his own method of teaching chemistry without atoms and molecules at the OEA in 1910. "The Science teachers of this Province, whether they admit it or not, owe a great deal to that little book of Dr. Lash Miller's, 'The Requirements,'" he stated. " . . . To most of us the mere idea that that the atomic theory did not have anything new to do with the facts or the laws of chemistry was so entirely new . . . that many, I fear, rejected it without even considering it. . . . Yet, it required but a few moments' reflection to show that this was perfectly sound, and those who had been taught in the old way marveled how this theory had blinded them so long."[89] Lehmann's remarks show that the new authorized textbook did not dictate a uniformly atomist pedagogy in Ontario's classrooms. They also show why Perrin's results—which were still trickling through the scientific community—were of little immediate consequence to chemistry teachers persuaded that the "facts and laws" of chemistry could be cleanly separated from the atomic theory.

Despite Perrin's research, the belief that the physical reality of atoms was fundamentally *unverifiable* proved to be resilient. This idea helped entrench the pedagogical principle that fact and theory should be demarcated. Writing in *School Science* in 1915, Ira Garard, a high school teacher from Grove City, Pennsylvania (and later a textbook author himself), stated that the atomic theory was an inherently speculative concept that could not be settled by evidence. Once students were well practiced in quantitative experiments, he

88. Quoted in Bensaude-Vincent, "Revisiting" (ref. 3), 19. On the dissemination of Perrin's results, see Crawford, "Arrhenius" (ref. 15), 508–509; Mary Jo Nye, chapter 4 in *Molecular Reality: A Perspective on the Scientific Work of Jean Perrin* (New York: Elsevier, 1972), 143–79.

89. Carl Lehmann, "The Teaching of Chemical Notation," *POEA* 49 (Toronto: William Briggs, 1910), 182–90.

wrote, teachers should explain that the atomic theory was the best accepted of many proposed hypotheses. “It should be emphasized,” he stressed, “that while all the facts support this theory, *it cannot be proved*; but the facts and laws are unalterable and cannot be affected by the proof or disproof of any theory.”[90] The inconclusive nature of theory set it apart from the resilience of experimental facts.

Eventually, however, the notion that the atomic theory was speculative or provisional quietly disappeared. I have come across no “conversion” statements, akin to Ostwald’s, among chemistry teachers. Yet there was a subtle shift in emphasis. A 1917 science teachers’ manual by George Twiss, for example, stressed that “if the pupils are allowed to begin talking and thinking in terms of the atomic theory before they have been inducted into the habit of starting their thinking with the facts of observation and experiment, the best part of the peculiar service that chemistry can render them through training in the scientific method of inductive inference will be lost.” Twiss worried that students would “speculate” about atoms and molecules, but not because they were hypothetical entities, as Lash Miller had argued. Rather, his emphasis was the distinction between fact and *inference*—that is, genuine understanding on the pupil’s part as opposed to dogmatic acceptance of what “scientists believe.” An ability to distinguish the two, he claimed, was a requisite of “any clear and scientific thinking.”[91]

In 1917, Ontario’s anonymous 1909 textbook, with its cautious statements of chemical atomism, was replaced with a new authorized textbook that clearly espoused physical atomism. The task of writing the new textbook was assigned to George Cornish himself, now a lecturer in the University of Toronto’s Faculty of Education. Cornish dispensed with any cautionary language about theory. His chapter on the atomic theory opened with a pointed epigraph from American poet Oliver Wendell Holmes: “[There are] one-story intellects, two-story intellects, three-story intellects with skylights. All fact-collectors, who have no aim beyond their facts, are one-story men. Two-story men compare, reason, generalize, using the labours of the fact-collectors as well as their own. Three-story men idealize, imagine, predict; their best illumination comes from above, through the skylight.” The atomic theory, Cornish wrote, *explained* chemical laws. Atoms were defined as physical entities: molecules were “the

90. Ira D. Garard, “Fact and Theory in Elementary Chemistry,” *SSM* 15, no. 1 (Jan 1915): 26–29, on 29 (my emphasis), doi:10.1111/j.1949-8594.1915.tb16236.x.

91. Twiss, *Principles of Science Teaching* (ref. 47), 362–81.

smallest existing particles of any substance" and were made of "still smaller particles called atoms." Ten years after his OEA address, Cornish codified his views about the role of theories in science, and the atomic theory specifically, in Ontario's authorized textbook.[92]

Notably, Cornish acknowledged Frank Kenrick's assistance in reviewing the entire manuscript. Their collaboration suggests that despite the resentment Cornish had initially expressed toward the Toronto chemists, this story is no simple showdown between high school teachers and university professors. Their cooperation on Cornish's explicitly atomist textbook is nonetheless surprising, because Kenrick staunchly advocated the use of laboratory terms in university teaching well into the 1930s. In his own 1932 undergraduate textbook, Kenrick still eschewed the term "atomic weight" along with a host of other standard terms.[93] The bemused and bewildered responses of the book's reviewers show just how atypical Kenrick's dogged empiricism had become.[94] But in the intervening years, Kenrick's approach had shifted too. Although he continued to stress precise language, earlier concerns about the explanatory power and hypothetical nature of the atomic theory were dropped. Kenrick argued that laboratory terms were essential because students' struggle to express definitions in clear language was one of the best forms of training in science.[95] This revised textbook positivism, now divorced from antiatomism, allowed Kenrick to retroactively recast Lash Miller's position on the atomic theory: "One misunderstanding," he wrote, " . . . is that Miller is thought to be opposed to the atomic hypothesis; he is only opposed to those who use the language of the hypothesis without understanding it."[96] An insistence on clear thinking had eclipsed the other,

92. George A. Cornish and Arthur Smith, preface and chapter 10 in *The Ontario High School Chemistry* (Toronto: Macmillan, 1917) (different from that cited in ref. 83); George A. Cornish and Arthur Smith, *The Ontario High School Laboratory Manual in Chemistry* (Toronto: Macmillan, 1917).

93. Frank B. Kenrick, *An Introduction to Chemistry* (Toronto: University of Toronto Press, 1932); see also Brook and McBryde, *Historical Distillates* (ref. 19), 96–98.

94. Kenneth L. Mark, review of *An Introduction to Chemistry*, by Frank B. Kenrick, *Journal of the American Chemical Society* 55 (Feb 1933): 801–2; William Foster, review of *An Introduction to Chemistry*, by Frank B. Kenrick, *Journal of Chemical Education* 10, no. 1 (Jan 1933): 61–62, doi:10.1021/ed010p61.2.

95. Frank B. Kenrick, "Are We Teaching the Right Chemistry?" *Canadian Chemistry and Metallurgy* 28 (Feb 1930): 45–46.

96. Frank B. Kenrick, "William Lash Miller Honoured by the King," *Chemical and Engineering News* 13, no. 23 (1935): 455.

now untenable currents of antiatomism that had once fueled the Toronto chemists' mission to reform beginners' pedagogy.

CONCLUSION

Debates about the pedagogical role of the atomic theory reached back to the mid-nineteenth century, but took on a new life in the first decade of the twentieth century in the United States and Canada. A new iteration of "textbook positivism," which emphasized experiment and aimed to keep theory in the background, found expression in turn-of-the-century high school chemistry textbooks. The new promoters of physical chemistry—who included Ostwald's students like Lash Miller, Kenrick, and Harry Clary Jones, as well as "converts" like Alexander Smith—advocated their own, evangelistic versions of textbook positivism that aimed specifically at downgrading or excluding the atomic theory. Allegedly "atom-centric" approaches needed to be replaced with a course attuned to the quantitative, experimental aspects of chemistry and the nature of chemical reactions. These chemists looked to high schools to cultivate an approach to chemistry that laid the groundwork for the expansion of physical chemistry. However, their ambitions hit up against the rapidly changing landscape of American and Canadian high schools. Rising enrollments prompted reform-minded educators to call for the emancipation of high school science from the universities' influence. A narrowly discipline-focused curriculum seemed fundamentally at odds with the priorities of a general education directed by the interests and needs of the average student whose education would end with high school. Smith's main concern about the place of the atomic theory in textbooks—namely, that it *misrepresented chemistry*—was out of sync with this new vision for high school education.

Although historians of education have devoted much attention to the changing dynamics of high school education in this period, little attention has been paid to the ongoing and varied discussions about the role of theory in science education. This case study is illuminating partly because educators shifted so seamlessly from arguments about the atomic theory to broad pedagogical prescriptions about scientific theory in general. But the dissent about the *atomic theory* specifically is revealing because it shows how turn-of-the-century educators grappled with whether and how to teach a theory that was not—and presumably could not be—definitively settled by evidence. Neither the established model of inductive scientific method nor the new discourse of educational psychology could tidily resolve this pedagogical question. Those on all sides of the atomism debate invoked induction to bolster their position, but the inductive method in a high school chemistry course could stop just short of theory (per Lash Miller and Smith) or *require* the atomic theory as its capstone (per Cornish). Likewise, everyone took for granted that beginners needed "concrete" concepts, but atoms could be conceived as either concrete or abstract.

The allegedly unprovable nature of the atomic theory further distanced pedagogical debates from any discussions about the evidence for or against physical atoms. It also allowed high school teachers, who in this period were beginning to assert a newfound professional identity, more agency in the debate, which might otherwise have been perceived as the jurisdiction of professional chemists. Cornish could even argue that truth or falsity of the atomic theory was irrelevant. Underscoring the high schools' mission to provide a general rather than pre-professional education, he argued that what high school graduates needed, not as future chemists but as informed citizens, was a "majority view" on the atomic theory. The Department of Education's textbook adjudication committee, pausing over *Chemistry for Schools*' "unusual" treatment of the topic, seemed to concur. High school teachers like Cornish and Peters turned the debate to the wider social significance of theory. A theoretical education could demarcate the "chemical laborer" from the beneficiary of a true general education. These teachers' insistence on the atomic theory's rightful place in the high school classroom implied that the atomic theory—and scientific theories in general—were *not* the preserve of the expert.

The historiography of science textbooks has often challenged the purported divide between the creative products of knowledge generation (like scientific research papers) and the conservative products of knowledge transmission and entrenchment (like teaching and textbooks). In the early historiography, including Gaston Bachelard and Thomas Kuhn, textbooks are firmly in the second camp, consolidating and disseminating disciplinary content. More recent historiography has challenged this dichotomy, pointing to the creative role of textbooks as manifestations of controversy, pluralism, and sometimes, dissent.[97] In the case of the atomic debates highlighted here, high school

97. See Bernadette Bensaude-Vincent, "Textbooks on the Map of Science Studies," *Science & Education* 15, no. 7 (Nov 2006): 667–70, doi:10.1007/s11191-005-1243-1; Belmar, Sánchez, and Bensaude-Vincent, "Didactic Writings" (ref. 2); John Hedley Brooke, "Introduction: The Study of Chemical Textbooks," in *Communicating Chemistry* (ref. 2), 1–18.

textbooks *did* help to consolidate an image of chemistry, and this was evident to everyone involved. Although individual textbooks—like *Chemistry for Schools*, the anonymous 1909 textbook, and Cornish's 1917 textbook—took different tacks with respect to atoms and molecules, the perceived stakes were the same: the image of chemistry and of science that would be delivered into the hands of beginners. This image was expected to play a double role, creating both a particular public perception of science and a particular kind of college preparation. This dual role exhibits the tensions between textbooks' role in popularization and disciplinary reproduction—tensions that were mirrored in the changing social role of high schools in the early twentieth century.[98]

In a 1910 *Harper's* article, "The Question of the Atom," University of Kansas professor of industrial chemistry (and University of Toronto alumnus) Robert Duncan claimed that resistance to the atomic theory was no longer about evidence, but about personal feelings and partisan interpretation. "The question 'is there an atom?' is as impossible to discuss in intellectual honesty as either politics or religion," he wrote. Duncan noted that dissention was particularly rife in the teaching of chemistry: "All this may be a surprise to the cultured layman, who probably takes his atoms, as he does his microbes, as a fact." The article set out to systematically review the case for the existence of atoms, so that the "cultured layman" reader of *Harper's* could judge for him- or herself. Duncan surveyed evidence from spectroscopy, the ultramicroscope, and Perrin's experiments—but it was Rutherford's experiments with alpha radiation and his compelling claim that alpha particles *were* helium atoms that provided, in Duncan's view, the strongest confirmation of the existence of atoms. This immense accumulation of evidence, he concluded, "permits us . . . to speak of atoms and molecules without a blush" and "to deprecate this business of writing text-books of elementary chemistry without the atomic theory. This has always been illogical and essentially absurd, and while after a certain fashion it may be accomplished, it has always worked to the serious hamperment of chemical instruction."[99]

Duncan's appeal to the readers of *Harper's* to adjudicate the evidence (and its attendant pedagogical disputes) illustrates how the atomic theory debates of

98. On the role of textbooks in history of science, see Adam R. Shapiro, "Between Training and Popularization: Regulating Science Textbooks in Secondary Education," *Isis* 103, no. 1 (2012): 99–110, doi:10.1086/664981; Kathryn M. Olesko, "Science Pedagogy as a Category of Historical Analysis: Past, Present, and Future," *Science & Education* 15, no. 7 (Nov 2006): 873–76.

99. Robert Kennedy Duncan, "The Question of the Atom," *Harper's Monthly Magazine* 121, no. 721 (Jun 1910): 113–19.

the early twentieth century played out in multiple spheres that included chemists, high school teachers, and an educated public. Although new evidence for atoms steadily accrued in the first decades of the twentieth century, the pedagogical debate was largely unaffected by these scientific developments. Despite Duncan's protestations, new evidence would dictate no radical change to pedagogical practice. In 1917, Cornish continued to advocate theory as a capstone of beginners' pedagogy, just as he had in 1907. Meanwhile, George Twiss's 1917 manual insisted on a sharp epistemological segregation of theory from fact, sustaining a tradition that reached back to the nineteenth century. These approaches could coexist both before and after Perrin and Rutherford's 1908–1909 research because battling conceptions of beginners' pedagogy had rhetorically distanced the pedagogical debate about the atomic theory from disputes about evidence. The reality of atoms was secondary to the purpose and symbolic value of introducing theories into the education of beginners.

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