LETTERS TO THE EDITOR

Letters are selected for their expected interest for our readers. Some letters are sent to reviewers for advice; some are accepted or declined by the editor without review. Letters must be brief and may be edited, subject to the author's approval of significant changes. Although some comments on published articles and notes may be appropriate as letters, most such comments are reviewed according to a special procedure and appear, if accepted, in the Notes and Discussions section. (See the "Statement of Editorial Policy" at http://www.kzoo.edu/ajp/docs/edpolicy.html.) Running controversies among letter writers will not be published.

ARE WE TEACHING SCIENCE AS PRACTICED BY SCIENTISTS?

Robert Millikan's[1] oil drop experiment to determine the charge of the electron has been the subject of considerable controversy.[2–4] Despite this, most general chemistry and physics textbooks consider it to be a beautiful and classical experiment in which data from the experiment unambiguously led to the formulation of the fundamental electrical charge (the electron). Millikan himself, despite the controversy with Felix Ehrenhaft, facilitated this impression, and a review of the literature shows that his handling of the data was controversial.[5] Most scholars would agree that Millikan's handling of the data was strongly influenced by his guiding assumption, namely, the existence of the electron and the magnitude of its charge.

Martin Perl,[6] Nobel Laureate in Physics (1995), has been working on the isolation of quarks (fractional charges). Perl and his colleagues have used a Millikan style methodology with improvements based on modern technology and stretching the normal present experimental boundaries. Given the difficulties involved in cutting-edge experimental work, he has designed a philosophy of speculative experiments in which he outlines his research methodology that includes reason and speculations (guiding assumptions). Speculative experiments become important when the scientist is groping with difficulties, future of the research cannot be predicted, and stakes are high due to competing groups (peer pressure). Perl and Lee have summarized this as:

> Choices in the design of speculative experiments [cutting-edge] usually cannot be made simply on the basis of reason. The experimenter usually has to base her or his decision partly on what feels right, partly on what technology they like, and partly on what aspects of the speculations [presuppositions] they like.[7] (Note: Phrases in brackets are added for clarification)

In a recent study we asked Leon Cooper (Nobel Laureate in Physics, 1972) to comment on Perl and Lee's methodology cited above. Cooper endorsed this methodology:

> Of course Perl is right. Pure reason is great. Experimentalists base their decision of what experiments to do on what feels right, what technology they're capable of using and their intuition as to what can be done and what might really be an important result. Experimentalists sometimes say that the first thing they try to do in an experiment is to make it work. It is intuition guided by facts, conjectures, and thoughts about what really would be important.[8]

This makes interesting reading, as Cooper goes beyond Perl and Lee by emphasizing not only speculations but also intuition guided by facts and conjectures. It is remarkable that even physicists now recognize in public (as contrasted with Millikan's methodology) that progress in science is not merely based on the accumulation of experimental data but rather dependent on the creative imagination of the scientific community, that is, guiding assumptions, intuition, facts, and conjectures.

In contrast to the interpretations of Cooper and Perl, science textbooks and curricula in most parts of the world continue to present progress in science as a product of experimental data that unambiguously lead to the formulation of scientific theories.[5,9,10] Similarly, the importance of students' epistemological beliefs in learning science has been recognized by Heron and Meltzer.[11] This should be cause for concern for most science teachers and especially those interested in motivating students to study science. Such a state of our textbooks is even more troublesome if in retrospect we consider what physicist-philosopher Gerald Holton[12] had warned almost four decades ago with respect to what he called the myth of *experimenticism* (scientific research as the inexorable result of the pursuit of logically sound conclusions from experimentally indubitable premises).

Finally, a historical reconstruction of various episodes and experiments shows that interpretation of experimental data is difficult, which inevitably leads to alternative models/theories, conflicts, and controversies, thus facilitating the understanding of science as a human enterprise.[5] Another example is provided by the photoelectric effect,[13] where Millikan accepted the experimental data and still rejected the underlying theory (Einstein's), which he considered to be reckless. At this stage it would be appropriate to pause and reflect as to why textbook authors, curriculum developers, and even some scientists ignore the historical record and do not teach science as practiced by scientists. It would seem that teaching science as practiced by scientists would be more motivating for students and thus facilitate a better understanding of progress in science.

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[1] R. Millikan, "The existence of a subelectron?," Phys. Rev. **8**, **595–625** (1916).

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[2] G. Holton, "Subelectrons, presuppositions, and the Millikan–Ehrenhaft dispute," Hist. Stud. Phys. Sci. **9**, **161–224** (1978).

[3] M. Niaz, "The oil drop experiment: A rational reconstruction of the Millikan–Ehrenhaft controversy and its implications for chemistry textbooks," J. Res. Sci. Teach. **37**, **480–508** (2000); M. A. Rodríguez and M. Niaz, "The oil drop experiment: An illustration of scientific research methodology and its implications for general physics textbooks," Instr. Sci. **32**, **357–386** (2004).

[4] M. Niaz, "An appraisal of the controversial nature of the oil drop experiment: Is closure possible?," Br. J. Philos. Sci. **56**, **681–702** (2005).

[5] M. Niaz, *Critical Appraisal of Physical Science as a Human Enterprise: Dynamics of Scientific Progress* (Springer, Dordrecht, 2009).

[6] Perl has now abandoned his active quark research (SLAC-PUB-13512, Jan. 2009).

[7] M. Perl and E. R. Lee, "The search for elementary particles with fractional electric charge and the philosophy of speculative experiments," Am. J. Phys. **65**, **698–706** (1997).

[8] Reproduced in Ref. 5, p. 171.

[9] M. Niaz, "Do we need to write physical science textbooks within a history and philosophy of science perspective?" in *Science Education in Focus*, edited by M. V. Thomase (Nova Science, New York, 2008), pp. 15–65.

[10] F. Abd-El-Khalick, M. Waters, and A. Le, "Representations of nature of science in high school chemistry textbooks over the past four decades," J. Res. Sci. Teach. **45**, **835–855** (2008).

[11] P. R. L. Heron and D. E. Meltzer, "The future of physics education research: Intellectual challenges and practical concerns," Am. J. Phys. **73**, **390–394** (2005).

[12] G. Holton, "Einstein and 'crucial' experiments," Am. J. Phys. **37**, **968–982** (1969).

[13] Reference 5, Chap. 8.

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JOULE'S WATERFALL MEASUREMENTS: A GREAT STORY, BUT IS IT TRUE?

In a review of *Mere Thermodynamics* by Don S. Lemons,[1] Rex[2] passes on the story of how Joule supposedly measured, while on his honeymoon, the temperature difference between the top and bottom of a waterfall. This story is attributed to the young William Thomson (later Lord Kelvin) by Bent,[3] who notes that Joule "suggested that the water at the bottom of a waterfall should be warmer than at the top, for Niagara falls, 160 ft high, about one-fifth of a Fahrenheit degree." Lemons[4] is sufficiently skeptical to admit that this story is "possibly apocryphal." The temperature difference $\Delta T = 0.20\ ^\circ\text{F} = 0.11\ ^\circ\text{C}$ follows from setting $gh = c_w \Delta T$, where h is the height of the waterfall, c_w is the specific heat capacity of water per unit mass, and g is the acceleration due to gravity. I have searched Joule's writings in vain for any indication that he ever made these measurements. If he did, he seems not to have reported them, possibly for good reasons. The temperature increase because of conversion of gravitational potential energy into thermodynamic internal energy is smaller than the natural variation in air temperature with height (lapse rate[5]). If we take the average in the troposphere to be about $6.6\ ^\circ\text{C/km}$, we expect the air temperature at the bottom of a waterfall 160 ft high to be about $0.32\ ^\circ\text{C}$ higher than at the top. Lapse rates near the ground can be much greater (or of opposite sign). We also face knotty problems such as the extent to which water at the top and bottom is in equilibrium with the surrounding air, drag on falling water, temperature increases because of the roiling of viscous, turbulent water at the bottom of the falls, and evaporative cooling of spray. Niagara Falls is a very complicated system. $\Delta T = 0.11\ ^\circ\text{C}$ is the *maximum* temperature increase assuming water falling in free space without evaporation and that the entire potential energy difference appears as an internal energy increase solely of the water. Joule faced the formidable task of extracting a small signal in the presence of considerable noise. Until someone can provide a solid reference to his measurements (or repeat them), I will continue to believe that he never made them or, if he did, he prudently set them aside because they markedly disagreed with his predictions.

[1] Don S. Lemons, *Mere Thermodynamics* (Johns Hopkins U. P., Baltimore, MD, 2009).

[2] Andrew Rex, Am. J. Phys. **77**, **862–863** (2009), book review of Ref. 1.

[3] Henry A. Bent, *The Second Law* (Oxford U. P., New York, 1965), pp. 14–15. Bent quotes Kelvin but gives no reference, and I did not find anything in the first two volumes of Kelvin's collected papers, one co-authored with Joule.

[4] Reference 1, p. 27.

[5] The dry adiabatic lapse rate is $g/c_a \approx 9.8\ ^\circ\text{C/km}$, where c_a is the specific heat capacity of air per unit mass. This temperature profile corresponds to an atmosphere in neutral static equilibrium. Note the similarity with g/c_w used to obtain Joule's result. The average lapse rate often is taken as two-thirds of the dry adiabatic lapse rate.

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