EDITORIAL

Theme Issue Editorial 2006

The development of a common explanation for electric and magnetic phenomena represents a crowning achievement and a glorious unification of theoretical and experimental physics. It is difficult to imagine our society today without the technological advances that depend on our understanding of electromagnetism. Almost every field of science and engineering relies in some important way on our collective understanding of electromagnetic phenomena. Furthermore, the structure of electromagnetism as a prototype gauge theory has been the inspiration for the subsequent construction of quantum field theories that are the foundation of the standard model of strong and electroweak interactions.

Beyond the richness of its subject matter, electromagnetism represents a wonderful context for teaching the history of science. As we prepare to celebrate Franklin's 300th and Maxwell's 175th birthdays, we can imagine that if they were alive they would be very proud of the progress that has been spawned by their experimental and theoretical contributions. From the experimental characterization of electromagnetic phenomena by Franklin and Coulomb and the development of the electric and magnetic field concepts by Gauss, Ampère, and Faraday to the prediction of electromagnetic waves by Maxwell and the subsequent unified description of these phenomena via Einstein's special theory of relativity, the historical development of electromagnetic theory epitomizes the growth and maturation of modern science. It is instructive to consider how far we have come. Michael Faraday's apocryphal response to the query of Gladstone (or Peel, according to some sources) regarding the possible practical use of one of Faraday's discoveries, "Why sir, there is the probability that you will soon be able to tax it," resonates with the millions of cell phone users today all over the world.

In addition, electromagnetism is a fertile field for discussing deep issues in the philosophy of science. For instance, an important part of the evolution of ideas in electromagnetism was the debate between adherents to Ampère's positivist approach and those who subscribed to Faraday's views on the physical existence of magnetic lines of force. Positivists claimed that only empirically verified laws have a place in natural philosophy (which precluded the concept of field from serious consideration). On the other hand, Faraday argued eloquently for the need for the *physical reality* of a mediating agent for the observed action-at-a-distance.

Even though quantum electrodynamics has extended classical electromagnetic theory, classical electric and magnetic fields and the corresponding vector and scalar potentials still play profoundly important scientific and pedagogical roles. In particular, the relative conceptual and mathematical simplicity of the classical approach makes it the only practical method for analyzing many systems. Despite the success of QED, classical electrodynamics reigns supreme for engineers and physicists trying to solve most real world problems. In addition, the mathematical elegance with which Maxwell's four equations are able to express such a wide range of phenomena places classical electrodynamics in a unique pedagogical role. As the first complete and mathematically rigorous field theory that prospective physicists learn, electromagnetism serves as the quintessential model of a physical theory. This Theme Issue of the *American Journal of Physics* celebrates these roles.

We are grateful to the many authors who submitted manuscripts for the Theme Issue. These authors have provided an excellent collection of articles that address a wide range of topics from experimental and theoretical treatments to pedagogical studies. Several articles explore applications of the principles of electromagnetism to research in optics and biological systems. Others describe novel problems and/or experiments appropriate for undergraduate electromagnetism courses. In particular, we have included a number of articles that describe experiments whose theoretical treatment is both relevant and accessible to the upper-division undergraduate audience. We have included two articles that describe fresh approaches to understanding the origins of magnetic fields and the role of time in classical electromagnetism respectively. In addition, several articles focus on issues relevant to undergraduate teachers of electricity and magnetism. One of these articles looks carefully at how targeted visualization can improve student understanding of the connection between microscopic and macroscopic models of electromagnetic phenomena. Other articles examine the challenges faced by students learning electricity and magnetism and/or describe innovative curricula designed to address these challenges at the introductory and advanced undergraduate levels.

There are a number of important questions that the articles in this issue do not address directly. Because the major in physics is a gateway to a wide variety of careers and not just a stepping-stone for graduate school in physics, what should the role of the junior-level course in electromagnetism be? The answer to this question is different for every institution. However, there are a few questions that we need to ask to begin the process of evaluating and redefining the role of electromagnetism in the physics curriculum. What are our goals for a course in electromagnetism? What topics should we be teaching? What teaching methods are most appropriate for achieving our curricular goals? To what extent should specific applications be incorporated into this traditional bastion of abstract theory? Who should be learning advanced undergraduate electromagnetism? Should we broaden the audience for this course beyond physics and electrical engineering majors to make the material more accessible to students of other sciences? Should we modify our introductory physics course to ensure that these students are exposed to an appropriately broad and deep treatment of electricity and magnetism? We owe it to ourselves and future generations of physics students to engage in a broad debate about these issues.

Classroom teachers, research physicists, and physics education researchers each have a unique role to play in this discussion. Classroom teachers bring to this discussion a perspective on what material is appropriate and relevant to students. The classroom teacher can most easily see what topics and applications are effective at motivating students to learn physics. The perspectives and opinions of physics researchers are also particularly important because as workers on the frontlines of modern research, these physicists are uniquely aware of the future needs of the field. In addition, these researchers are often most in touch with how physics is being applied in sciences outside the traditional realm of physics. Researchers in physics education need to be at the table not just as scholars who investigate what students can and cannot do after traditional or modified instruction, but also as innovators who identify promising new frontiers in teaching and in so doing challenge the boundary conditions that define what and how we currently teach.

We hope that a forum in which these and related topics can be discussed is the upcoming Gordon Research Conference on Physics Research and Education: Electromagnetism, to be held June 11–16, 2006, at Mount Holyoke College in Massachusetts. The goal of the 2006 conference is to bring together physics researchers, physics education researchers, and university and college instructors of electromagnetism and optics for the purpose of promoting innovation in all aspects of teaching electromagnetism throughout the undergraduate curriculum. The conference will include discussions of appropriate course content, novel teaching methods and innovative approaches to nonintuitive aspects of the subject matter, the role of computers and technology in the curriculum, results of physics education research, and current research results that may be woven into undergraduate courses in optics and electromagnetism.

As the fourth in a continuing series of Gordon Research Conferences on physics research and education, this conference is an excellent forum for discussing the most important issues associated with the teaching of electromagnetism. For more information about the upcoming conference, please visit ⟨http://www.grc.org/programs/2006/physres.htm⟩.

In closing, we thank Jan Tobochnik, Editor of the *American Journal of Physics*, Harvey Gould, the Associate Editor, and Dan Schroeder, Book Review Editor, for their invaluable contributions in putting together this Theme Issue. Their professionalism kept us on track and made this process enjoyable.

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2006 GORDON RESEARCH CONFERENCE ON PHYSICS RESEARCH AND EDUCATION: ELECTROMAGNETISM
June 11-16, Mt. Holyoke College

OPENING SESSION: Robert Hilborn (Amherst College), **David Griffiths** (Reed College), **Bill Dorland** (University of Maryland)

CURRICULAR APPROACHES TO ELECTRICITY AND MAGNETISM: Tom Moore (Pomona College), **Ruth Chabay and Bruce Sherwood** (North Carolina State University), **Igal Galili** (Hebrew University of Jerusalem), **Bruce Patton** (The Ohio State University)

APPLICATIONS OF ELECTRICITY AND MAGNETISM IN BIOLOGICAL AND MATERIAL SCIENCE RESEARCH: Lydia Sohn (University of California, Berkeley), **Brent Hoffmeister** (Rhodes College), **Laura Clarke** (North Carolina State University)

PHYSICS EDUCATION RESEARCH IN ELECTRICITY AND MAGNETISM: David Maloney (Indiana University-Purdue University), **Peter Shaffer** (University of Washington), **Robert Beichner** (North Carolina State University), **Stephen Kanim** (New Mexico State University)

HISTORICAL PERSPECTIVES ON ELECTROMAGNETISM: Joe Redish (University of Maryland), **Dan Siegel** (University of Wisconsin), **Bob Morse** (St. Alban's School)

APPLICATIONS OF ELECTROMAGNETISM IN ATMOSPHERIC AND ASTROPHYSICAL RESEARCH: Kristina Lynch (Dartmouth College), **Michael Brown** (Swarthmore College), **Ramon Lopez** (Florida Institute of Technology), **E. Philip Krider** (University of Arizona)

APPLICATIONS OF ELECTROMAGNETISM IN MODERN OPTICS RESEARCH: Charles Holbrow (Colgate University), **Gabriel Spalding** (Illinois Wesleyan University), **Enrique (Kiko) Galvez** (Colgate University)

COMPUTER SIMULATIONS FOR TEACHING OPTICS AND ELECTROMAGNETISM: Wolfgang Christian (Davidson College), **John Foley** (Mississippi State University), **John Belcher** (Massachusetts Institute of Technology), **Noah Finkelstein** (University of Colorado)

THEORETICAL AND MATHEMATICAL CHALLENGES TO LEARNING ELECTRICITY AND MAGNETISM: Chandralekha Singh (University of Pittsburgh), **Rachel Scherr** (University of Maryland), **Corinne Manogue** (Oregon State University)