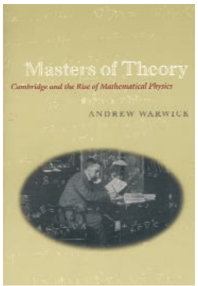
Masters of Theory: Cambridge and the Rise of Mathematical Physics

Andrew Warwick
U. of Chicago Press, Chicago, 2003. $85.00, $29.00 paper (572 pp.). ISBN 0-226-87374-9, ISBN 0-226-87375-7 paper



In *Masters of Theory: Cambridge and the Rise of Mathematical Physics*, Andrew Warwick, a senior lecturer in the history of science at Imperial College London, focuses on the development of a community of University of Cambridge mathematical physicists during the 19th and early 20th centuries. Except for two case studies, Warwick's attention in the book is not on research but on the methods of teaching at the university, the kind of mathematics taught, and, through that training, the emergence of a group of researchers united by standards and expectations developed while they were students.

The training at the university was intense. It entailed three years of instruction in mathematical and physical principles, accompanied by practice in using those principles to solve technical problems of growing difficulty as quickly as possible. The prize was the position of First Wrangler in the Cambridge Mathematical Tripos, a grueling examination, held over several days, in which mathematical problems of increasing sophistication were posed. Grading depended on accuracy and the number of questions answered at each stage in the examination. A student's place in the honor role determined reputation and career possibilities. This was a contest of national importance.

This method of training was unique to Cambridge and, as Warwick argues, grew out of the particular social circumstances in the university. It led to a community of researchers who shared common problems, standards, and methods. To put meat on this argument, Warwick investigates the research that emerged from James Maxwell's *Treatise on Electricity and Magnetism*. It took a decade for Cambridge mathematicians to understand Maxwell's physical ideas and mathematics and incorporate them into their teaching and questions for the Tripos examination. By 1900, that research had gone far beyond Maxwell's equations to include work on an electrodynamic foundation for physics. In many ways, the direction paralleled the research done contemporaneously in Europe. The unique training at Cambridge led to a style of research that generated increasingly complex mathematical problems. Yet the physics was not stagnant; the relativity of motion was recognized and explored. In the early 20th century, some researchers saw the ether as doubtful or superfluous.

This nuanced account of the beginning of relativity theory leads Warwick to present a bold new interpretation of the reception of Albert Einstein's papers on relativity. Warwick contends that physicists need to set aside the idea that physics was in crisis or moribund around 1900. Einstein cannot be seen as an isolated genius but as a young theoretician who, in 1905, contributed to the flourishing field of electrodynamics. In Cambridge, reactions to his denial of the ether were negative, not from conservatism but from Einstein's lack of demonstration—experimental or mathematical—of the idea's plausibility. No one saw his arguments on relative motion as extraordinary. It was not until Hermann Minkowski reworked Einstein's ideas in 1909 that the term "theory" of relativity entered physicists' vocabulary.

Einstein's work on general relativity was not appreciated until after 1916 (partly because of World War I) through Willem de Sitter's interpretation. The grounds of the theory and the debate then shifted from electrodynamics to astronomy, a shift that presented Cambridge mathematicians with difficulties. The mathematics of general relativity was not part of the Tripos and, in general, not known to most theoretical physicists. The efforts of astrophysicist Arthur Stanley Eddington significantly changed mathematics and physics at Cambridge. Because of Eddington's report on general relativity and astronomy in 1918, his books on general relativity, and his courses, the mathematics and physics of general relativity entered into Cambridge's curriculum and thus into the Tripos examination.

Teaching was central to the creation of the Cambridge group and, Warwick contends, to any research community, whether local, national, or global. Thus Warwick's work is of interest to physicists and historians. He introduces the sobering example of specialties disappearing, not because they were destroyed by new theories but because no one taught them anymore and their subject matter no longer appeared on examination papers. Teaching creates research fields and is the glue that keeps physics together. A decline in teaching will signal the decline of the discipline and profession itself. It is also a sobering thought, as Warwick points out, that the riches of our common heritage will disappear not through destruction from without but through neglect from within.

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Principles of the Quantum Control of Molecular Processes

Moshe Shapiro and Paul Brumer
Wiley, Hoboken, NJ, 2003. $83.95 (354 pp.). ISBN 0-471-24184-9

The field of quantum control has a long history. In the early 1970s, it was thought that tunable lasers, those novel coherent light sources, might be able to break molecular bonds selectively and thus enable radically new methods for chemistry. Unfortunately, molecules are remarkably adept at quickly redistributing any applied laser energy among many modes of internal motion, so the laser acts more like a blowtorch than a surgical scalpel on the atomic scale. Mode-selective chemistry was a failure.

But in the mid-1980s, the field began a remarkable revival that continues today. Two different methods were proposed independently at that time to overcome the intramolecular vibrational redistribution problem. Both methods were based on laser-coherence improvements that made it possible for scientists to control optical phase over a broad spectral range. These two control protocols are known in the field by the names of their originators: Paul Brumer and Moshe Shapiro, for the Brumer–Shapiro scheme, and David Tannor and Stuart Rice, for the Tannor–Rice scheme. Together with continued improvements in lasers, optical pulse shaping, and calculation techniques, these two methods have rejuvenated quantum control of molecules to the point where the topic has generated hundreds of papers, dozens of active groups, and several international conferences. Now, Shapiro and Brumer have written a textbook, *Principles of the Quantum Control of Molecular Processes*, that is intended to educate

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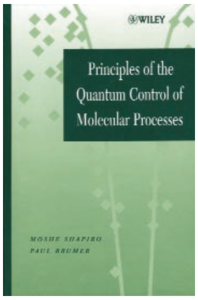
a new generation of researchers in the basics of quantum control.

The book is certainly timely because the field is rapidly becoming too wide to encompass the fundamentals of quantum control in a single monograph. Shapiro and Brumer's book begins with a brief but pedagogical two-chapter review of laser–matter interactions, with a particular emphasis on photodissociation. Virtually no steps are left out, so graduate students or their professors will have no trouble following the detailed derivations.



The essence of the book begins with chapters 3 through 5. Chapter 3 describes the Brumer–Shapiro route to quantum control, in which the final state specificity comes from the interference between multiple pathways in multiphoton transitions from the initial to the final states. This method emphasizes the role of phase coherence in the control mechanism. The first section of chapter 4 covers the Tannor–Rice scheme in which control is achieved with multiple ultrafast optical pulses. The first "pump" pulse promotes the molecule to a nonstationary excited state, where it evolves for a time and is then de-excited to the desired final state by a second "dump" pulse.

By putting the two schemes in separate sections of the book, Brumer and Shapiro can explain each scheme using its own natural language; that is, they describe the Brumer–Shapiro control as multimode interference between stationary states and the Tannor–Rice control as wavepacket evolution of nonstationary states. These quantum control schemes are concepts rather than prescriptions. In fact, in many respects, they are just two different views, temporal and spectral, of the same process. This commonality is explored in section 3.5.

In a typical polyatomic molecule, which has dozens or more coupled modes and is immersed in a solvent or embedded in a solid at room temperature, the specific path to control is far from clear. The field of quantum control would not have blossomed were it not for the pioneering development of feedback search strategies, one of the great stories laid out in this book. Calculations have yielded control fields even in the presence of many modes and decoherence pathways through the use of optimal control theories (for example, by Herschel Rabitz, Ronnie Kosloff, Tannor, and many others). Experiments have yielded, through programmable pulse shaping and learning algorithms, complicated field solutions involving hundreds of different amplitude- and phase-controlled frequencies. Understandably, Shapiro and Brumer spend more pages on the theoretical challenges and calculation techniques than on the experimental methods. The second half of chapter 4 contains a tutorial on optimal control theory, which I found particularly useful and lluminating. Chapter 5 discusses the most important aspects of decoherence and loss of control.

Chapters 6 through 8 survey the field of quantum control. They contain several case studies covering calculations or experiments that demonstrate two-color control, control of chaotic dynamics, control of bimolecular processes, and control to achieve chiral selectivity. Even though it only skims the surface of the work that has been done in the field, the material in these chapters is interesting and useful. Chapter 13, "Case Studies in Optimal Control," could easily have gone in this part as well.

The last part of the book, chapters 9 through 13, goes beyond the weak-field limit to explore control problems for which lowest-order perturbation theory is inappropriate. Here, the book cannot even be a comprehensive introduction, because the range of topics and list of observed phenomena are too vast. Rather, the authors choose several topics and explore each briefly. Shapiro and Brumer's style is to stick to problems in which simple analytical techniques can give physical insight. Chapter 9 covers stimulated adiabatic population transfer problems, electromagnetically induced transparency, and lasing without inversion—problems that can all be understood using few-level coupled systems and dressed-state formalism. Chapters 10 and 11 cover some problems in photodissociation and continuum–continuum transitions. In all cases, the book is distinguished by its clear derivations.

In chapter 12, the focus moves to the strong-field regime where the laser electric-field amplitude becomes comparable to the binding fields in the molecule. Oddly, the chapter begins with the quantization of the electromagnetic field even though calculations in the strong-field regime do not require this field quantization. Nonetheless, the chapter goes on to good discussions of some problems of current interest, most notably molecular-bond softening and molecular focusing and alignment due to light-induced potentials. But the authors do not mention standard approaches to strong-field interactions, such as Keldysh-Faisal-Reiss theory or the rescattering model, and they also do not mention above-threshold ionization or high harmonics in molecules. Those subjects have contributed to the general field of quantum control. Even basic concepts like the ponderomotive potential are not covered. Perhaps, though, it is too much to expect a single volume on quantum control to cover all of the territory. Any weakness in chapter 12 does not detract much from the main strength of the book, which is a thorough treatment of weak-field quantum control.

My overall impression of *Principles of the Quantum Control of Molecular Processes* is extremely positive. In fact, I would like to use the book as a basis for a graduate course on quantum control, and I recommend it to anyone who wishes to know more about the subject. Shapiro and Brumer have been pioneers in the field for 20 years, and the book is another impressive contribution from them.

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Ink Sandwiches, Electric Worms and 37 Other Experiments for Saturday Science

Neil A. Downie
Johns Hopkins U. Press, Baltimore, MD, 2003. $45.00, $18.95 paper (334 pp.). ISBN 0-8018-7409-2, ISBN 0-8018-7410-6 paper

At the University of British Columbia, we run a fourth-year physics course in which students who are interested in a teaching career learn how to build physics demonstrations and present them in schools. Thus we are always on the lookout for suitable projects that are eye-catching, inexpensive, and yet pedagogically solid. *Ink Sandwiches, Electric Worms, and 37 Other Experiments for Saturday Science* by Neil Downie has many good ideas.

Most of the projects Downie presents were developed over years of involvement with a Saturday morning children's club in his hometown of