History of Modern Chemistry entitled, *From the Test-tube to the Autoanalyzer: The Development of Chemical Instrumentation in the Twentieth Century* held in August of 2000 at the Science Museum of London, previously reported in this journal (*Hyle*, 7 [2001], 78-81) and published in a book edited by Peter Morris, *From Classical to Modern Chemistry: The Instrumental Revolution* (Royal Society of Chemistry, 2002) (see Daniel Rothbart's book review in the present *Hyle* issue).

In conclusion, *Instruments and Experimentation in the History of Chemistry* is an important early step in recognizing the experimental nature of our science. Any rigorous investigation into chemistry's experimental roots must include an analysis of the instruments involved. This is superbly summarized by Mauskopf when he states, "Sometimes, indeed, even conceptually separating experimental techniques and instruments from theories is difficult" (p. 354). Although some of the included papers are presented in incomplete form, the book as a whole presents a coherent analysis of its subject matter. It will make a fine addition to the bookshelf of anyone interested in the experimental aspects of chemistry's roots, as well as institutional libraries.

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THE REVOLUTION IN INSTRUMENTATION

From Classical to Modern Chemistry: The Instrumental Revolution, ed. by PETER J. T. MORRIS, The Royal Society of Chemistry, Cambridge, 2002, xxv + 347 pp., £75.00 [ISBN 0-85404-479-5].

The maxim that technological discoveries are derived from theoretical advances in pure research cannot account for the twentieth-century revolution in instrumentation. The transition in research techniques from 'wet chemistry', for example, to a chemistry driven by the fingerprinting techniques of electronic instrumentation had a profound effect on 'pure research'. More significantly, the alleged privilege given to pure researchers over instrument makers is undermined as the close relationship between instruments and their experimental results emerges. This instrumentation revolution was waged in the offices, conference rooms, and laboratories of the chemical industry, responsive to the needs of manufacturers, government agencies, and military institutions; and these are the themes explored in a recently released work, *From Classical to Modern Chemistry: The Instrumental Revolution*.

All but three of the chapters in this volume are revisions of presentations at a conference held at Imperial College, London, in August 2000. The volume is well organized by the editor, PETER J. T. MORRIS, and the high level of scholarly rigor exhibited in these pages reflects the expertise of the authors. The reader will be richly rewarded by this fine work, finding depth in the case studies of various instruments and breadth in the range of ideas related to the science/technology interaction in chemistry. Many of the instruments examined in this volume are identified as research technologies, to use TERRY SHINN's phrase.

The strength of the volume emanates from the richly detailed studies of creative chemists, and in some cases industrialists, who hastened the instrumentation revolution. YAKOV RABKIN provides an excellent study of the discovery and refinement of infrared spectrometers born out of research in industrial companies. Between the two world wars, the infrared spectrometer became a commonplace tool in industry, particularly in the synthetic rubber program and for petroleum refinement. Rabkin shows how this technique also became a routine tool of organic chemistry, following advances by the German chemical industry before World War II and the British and American companies after the war.

A fascinating study of NMR spectroscopy is given in a chapter by PETER MORRIS and ANTHONY TRAVIS. These authors demonstrate how the petrochemical industry worked closely with university centers in efforts to discover techniques for converting certain physical processes to spectra. Important advances in NMR spectroscopy were achieved by scientists at Stanford, and independently at Harvard, immediately after World War II, leading to a 'paradigm-shift' in organic chemistry. The central importance the chemical industry to breakthroughs in instrumentation is also documented by CHARLOTTE BIGG in her study of Adam Hilger, Ltd. Under the leadership of Frank Twyman, Hilger introduced chemists to many of the new instruments of the century by discovering how to convert complex techniques to routine material practices for research. This discovery was achieved by translating practices from physics to chemistry.

DAVID KNIGHT shows how the instrumentation revolution of the 1950s and 1960s led to fundamental changes in the profession of chemistry. He places the instrumentation revolution in historical perspective, reminding the reader of other episodes in which innovations in the tools of research generated advances in chemistry. The centrality of instrumentation to the identity of the profession of chemistry is documented in two chapters by DAVIS BAIRD. According to Baird, the instrumentation revolution transformed the standards for chemical knowledge based on discoveries in the engineering of instruments. Chemical knowledge is judged more on research techniques associated with manipulating and controlling materials than on the theoretical representations of microscopic processes that presumably provide the rationale for such techniques. Baird provides a richly detailed history of Baird Associates, founded and managed by his father, Walter Baird. A well-known manufacturer of analytical instruments, with cutting edge contributions to emission and infrared spectroscopy in the 1930s and 1940s, Baird Associates illustrates how the instrumentation revolution changed forever how scientific knowledge is acquired, and how science and technology are mutually supportive.

In another study of instrumental innovations, CARSTEN REINHARDT documents the development of mass spectroscopy, motivated in large measure by the chemical and petroleum industries during World War II. NICOLAS RASMUSSEN explores the development of the electron capture detector as a case study for broader issues in science and technology. This instrument is also examined in a fascinating article by PETER MORRIS, who shows its importance for responses to the environmental disaster of DDT in the 1950s. LUIGI CERRUTI provides an informative study of the instrumental techniques of medical genetics, centering on research in abnormal hemoglobin. ANTHONY TRAVIS provides further documentation for the importance of the chemical industry in developments in instrumentation with his study of American Cyanamid. In "Production Control Instruments in the Chemical and Process Industries", STUART BENNETT identifies production control devices as an important component of research technologies. Such devices offer general insight into instrumental technologies, not merely as tools to be exploited for research but as engineering systems designed to solve problems of measurement and control.

How can the instrumentation revolution be explained? In many chapters, we read how the invention, development, and achievements of any particular instrument are driven by social, economic, and in some cases political factors, giving prominence to the practices of analytical chemists, industrialists, and technicians. Of course, any adequate explanation of the instrumentation revolution should address certain important theoretical developments in techniques for converting physical processes into spectra. The stunning technological advances in instrumentation of the 1940s and 1950s were guided by discoveries of the ways in which molecules are held together, bonds are formed and broken, and reactions occur at the molecular level. In his outstanding essay, LEO SLATER shows how advances in structure theory, particularly from the contributions of Nevil Sidgwick in the 1930s and Robert Burns Woodward in the 1940s, provided instrument makers with new cognitive tools. The traditional demarcation between the material of chemistry (the pure compounds, liquids, crystals, etc.) and the representations of chemical structures was undermined, as the organic chemists now moved effortlessly from structures to materials and back again.

A major theme of this work is the profound transformation that this revolution brought to the profession of chemistry and the mission of researchers. In an excellent article on this topic, JOACHIM SCHUMMER argues that the instrumental revolution is responsible for a profound change in the chemists' ontological attitude, leading to a revision of the goals of chemical theory. The huge increase in the number of new chemical "substances," from 120,000 in 1900 to nearly one million in 1950, undermined the traditional commitment to chemical substance as the primary subject matter of research. With the revolution in instruments, chemistry changed from a study of substance to a study of structures.

PIERRE LASZLO objects to Schummer's ontologically focused explanation, arguing instead for a sobering look at the personal and professional motives for using apparatus in general. For Laszlo, the display of laboratory tools is rationalized by epistemic pretensions about their purpose, masking their actual function as rhetorical devices. He defines instruments as inscription devices for constructing the texts of science. Rather than revealing the real-world properties of atoms and compounds, the new devices are used for prestige and power, as chemists proudly show off their contraptions to visitors, or advertise their techniques to journal referees. The so-called revolution in instrumentation enhances the mystique of researchers, and perpetuates a professional myopia, as he put it, about the rhetoric of chemistry.

Many of the authors in this book stress the need to persuade chemists, whether in industry or academia, that the new instrumental techniques are reliable, and the resulting spectra are valid. In my opinion, this task is aided by the design plans of the physical chemists who invented such devices, providing researchers with visual models of the material features of the apparatus, as a system of metals, plastics, and chemicals. Of course, such plans also offer guidance in instrumental techniques by depicting the opportunities and limitations of using the device. Included in the rationale for the instrument are models of the physical processes that are responsible for generating experimental phenomena and producing valid signals. For example, Gerd Binnig and Heinrich Rohrer, both working for IBM in Zurich, won the Nobel prize in 1983 for the invention of the scanning tunneling microscope, which is commonplace in analytical chemistry today. To show the tunnel effect through a barrier between two metals, Binnig and Rohrer provided a thought experience in their 1982 patent, filed with the United States Patent Office (G. Binnig, & H. Rohrer: 1982, 'United States Patent: Scanning Tunneling Microscope, August 10, 1982', Assignee: International Business Machines Corporation, Armonk, NY. Patent Number: 4,343,993, figure 1, sheet 1). The design plans for scanning tunneling microscopes by Binnig and Rohrer offer readers a model of electron tunneling. From the perspective of energetics, the electron travels to a surface atom by tunneling *through, but not over*, the energy barrier (G. Binnig & H. Rohrer: 1985, 'The Scanning Tunneling Microscope', *Scientific American*, August, pp. 50-56). Readers are often convinced via these plans that they *could* reproduce the same processes, as if they could re-enact significant features of the experiment. Underlying the rhetorical function of such design plans are models of quantum mechanics, offering chemists a justification for adopting revolutionary instruments, and a basis for profound changes in research techniques.

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Teaching Philosophy of Chemistry at the University of Exeter

Teaching an undergraduate course in Philosophy of Chemistry to chemists provides many challenges since few academic subjects are more different in their way of thinking (*e.g.* their approach toward truth, their language, formalism), teaching and, communication style. In October 1999 the School of Chemistry at the University of Exeter (UK) has introduced an optional course in 'History and Philosophy of Chemistry' for 2nd and 3rd year chemistry undergraduates. This course has since been growing in popularity among students and its philosophical component now consists of 11 lectures with additional 40 hours associated study-time for revision and background reading. The curriculum has also been continuously updated to provide students with philosophical concepts relevant to – and also exemplified by – chemistry.

The current syllabus addresses three philosophical topics: theory of science, logic of arguments, and ethics. The first part covers basic concepts of epistemology such as scientific reduction, scientific versus logical truth, verification, falsification, and methods of scientific inference (induction and deduction). The second part discusses the systematic logical analysis of chemical reasoning, a technique that complements the traditional literature review students already undertake in chemistry. The ethics section introduces the concept of responsibility, explains utilitarian and normative approaches toward chemical research (*e.g.* chemical weapons research and medical drug design, testing of chemicals, and distribution of resources). It also illustrates Kant's categorical imperative in moral conflict situations and looks at the role of casuistic learning of 'ethical behavior' during practicals, case studies, and undergraduate research projects. Although there is no specific textbook for this course, basic philosophical literature, some of which even uses ex-