From the “Chemical Museum” at Leeds,
founded in 1874 (courtesy of the
University Collection, University of Leeds.)

# Independent Research Group I

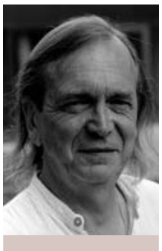
## History and Philosophy of Laboratory Sciences

Director: *Ursula Klein*

### Project 1

## Materials in the History of Science and Technology (ca. 1600 – 1850)

*Ursula Klein, Andrew Pickering, Maria Rentetzi, Leo Slater, Andrew Sparling*


Andrew Pickering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Leo Slater


Andrew Sparling

In the past two decades, historical studies of the relations between the experimental and observational sciences and the arts and crafts, or technology, have placed instruments at the forefront of historical inquiry. Such studies, as well as more general accounts of the reconfiguration of learned knowledge and practice from the seventeenth century until the nineteenth century, have demonstrated the extent to which the generation of learned natural knowledge crucially depended on instruments understood as resources constructed out of, and working upon, wider technology and society. The project "Materials in the History of Science and Technology" shifts attention towards a new kind of material objects: raw materials and substances processed in the workshop and laboratory. Well into the nineteenth century metals, salts, dyestuffs, gunpowder, ceramics, porcelain, glass, vegetable substances, alcoholic liquors, mineral waters and so on were simultaneously commodities and objects of scientific inquiry. As they were objects shared by artisans and savants, they had many different significances and uses, according to how they were deployed in different practical or epistemic contexts. Traveling from sites of commercial production and consumption to academic institutions, and vice versa, they spurred the generation of both learned (or scientific) and artisanal (or technological) knowledge.

Focusing on materials, the project further moves from institutions and activities that have been unambiguously viewed as typical of “experimental philosophy” towards sites at which the practice of the arts and crafts intersected with many different types of learned culture. This dual shift broadens our notion of material culture by taking materials seriously as the subject of historical knowledge, and further suggests some revisions to the standard historical picture of the emergence of the natural sciences. A viewpoint still powerful within the field of history of science, which situates experimental philosophy and the history of physics at the center of attention, is replaced here by a decentered approach that takes into account a broader range of forms of making and knowing in the history of science and technology, including natural history, chemistry, pharmacy, and medicine. All of these latter cultures resist clear categorization under the rubric of “experimental philosophy.” By analyzing the making, uses and meanings of materials between 1600 and 1850, the project examines how different cultures of natural history, experimental history *(historia experimentalis)*, and experimental philosophy intersected with artisanal labor and craftsmanship and with practices of commerce and consumption.

## Book

(by *Ursula Klein* and *Wolfgang Lefèvre*, Department I): *Materials in Eighteenth-Century Science: A Historical Ontology.* Cambridge, Mass. and London: MIT Press, in press

The book presents a novel approach to the history of scientific objects in general, and the history of chemistry in particular. It interweaves three historical and philosophical themes: ontologies of materials, practices of identifying and classifying materials, and the science of materials from the late seventeenth century until the early nineteenth century.

In the eighteenth century the science of materials was chemistry. Though learned inquiries into materials also took place in mineralogy, botany, architecture, engineering, pharmacy and a few other areas, chemistry was the only scientific culture in the eighteenth century where materials were studied persistently, comprehensively, and from multiple perspectives. The material substances studied by eighteenth-century chemists were for the most part commodities procured, sold, or tested in apothecary’s shops, foundries, assaying laboratories, arsenals, dyeing manufactories, distilleries, coffee shops and so on. Even the few substances that were genuine inventions or discoveries of the academic laboratory were soon transferred to the mundane world, where they found application as remedies and other goods. But chemists also studied substances as natural objects that carry imperceptible features. They invested commodities with new meaning when they ordered them according to natural origin, analyzed their invisible components, and explored their affinities in chemical transformations. In so doing, chemists constituted objects of scientific inquiry that reached out to cultures of natural history and experimental philosophy.

Eighteenth-century chemistry often has been studied as a science of atoms, corpuscles, and Newtonian forces. In contrast, the authors' approach depicts the chemistry of that period as a science of materials. They argue that chemically processed substances and natural raw materials played such a central role in eighteenth-century chemistry because they lent themselves to multifarious ways of inquiry: descriptive (in the *historia* tradition), technological, and philosophical. Historical studies of materials allow a new grasp of issues traditionally highlighted as characteristic of the science of chemistry—composition, affinities and similar entities akin to the imperceptible objects of experimental philosophy—alongside themes traditionally treated as characteristic of natural history and as centerpieces of chemical technology. A larger picture of chemistry from the late seventeenth century until the early nineteenth century is obtained, outlined with broad strokes but extending from its mundane artisanal practices to experimental and natural histories, all the way to conceptual or philosophical inquiry. Eighteenth-century chemical substances were multidimensional objects that were investigated in practical and theoretical contexts, and amalgamated perceptible and imperceptible, useful and philosophical, technological and scientific, social and natural features. Their many faces challenge our current predominant philosophical and historical understanding of scientific objects, which sets apart objects of scientific investigation from objects of technological inquiry, and objects of a descriptive natural history from objects of explanatory natural philosophy.

The book's main approach to eighteenth-century chemists' ontology of materials is the scrutiny of their practices of identification and classification. Identifying and classifying things are human activities that structure the world by ordering single things into kinds of things and by establishing relationships between the different kinds. Studies of classifications inform historians of what types of objects were handled in the past and how the historical actors understood these objects; that is, they lay bare the rough ontological structures of the past. In the course of the eighteenth century, chemists' ontology of materials shifted in various ways in keeping with changes in their classificatory practices. For example, until the middle of the eighteenth century chemists regarded plant materials primarily as remedies; in keeping with pharmaceutical classification they ordered plant materials into two different classes, namely, the pharmaceutical simples purchased from merchants, such as sugar, camphor, natural balsams, wax, gums, and resins, and the chemical remedies prepared in their laboratories, such as distilled oils, distilled waters, extracts, and essential salts. Around the middle of the eighteenth century they epistemically elevated plant materials as compound components or proximate principles of plants, while grouping together the pharmaceutical simples and the chemical remedies into the unified class of proximate principles of plants. Some four decades later they began to highlight "organic substances" created by processes of life, grouping together proximate principles of plants and of animals. Yet beginning in the late 1820s many of these early organic substances, such as balsams, distilled vegetable oils and animal fats, disappeared from chemists' agenda, and were replaced by a new type of scientific objects, namely the stoichiometrically pure carbon compounds that were classified according to chemical composition and constitution represented by chemical formulae.

A striking result of the research on eighteenth-century chemical materials was the discovery of just how diverse eighteenth-century chemists' classificatory practices were. Eighteenth-century chemists did not order materials under a single conceptual umbrella or paradigm, and they did not create one comprehensive taxonomic system. Apart from the many different ways of classifying materials in contexts of technological inquiry or "applied chemistry," the book highlights two main differences in their ways of classifying materials in contexts of conceptual investigation: classification according to chemical composition, and classification according to provenance and perceptible properties. This striking difference in eighteenth-century chemists' mode of classification of materials informs the organization of the book and its division into two main parts—part II analyzing the domain of materials classified according to chemical composition, and part III studying plant materials classified according to natural origin, way of chemical preparation, and perceptible properties. A long introductory part I tackles historical and philosophical questions concerning the kinds of materials studied by eighteenth-century chemists, chemists' collective practices of studying these objects, and the uses of studies of classification for historians and philosophers of science. In a final conclusion we examine the role played by materiality for the existence and maintenance of the major difference in chemists' order of materials.

Speaking of eighteenth-century chemistry almost inevitably brings up the theme of the chemical revolution. The Lavoisierian chemical revolution of the last third of the eighteenth century has been one of the most debated themes in the history of chemistry. It also spurred controversies in the history and philosophy of science more broadly. If the assumption is right that eighteenth-century chemical substances were multidimensional objects of inquiry, which invited chemists to switch from studies of perceptible properties and commercial uses to studies of imperceptible features, the book's approach should also provide new insight into this crucial historical event. This is indeed the case. The two main historical studies presented in parts II and III of the book—the classification of pure chemical substances in the *Méthode de nomenclature chimique* of 1787, which has always been regarded as a central achievement of the chemical revolution, and chemists' classification of plant materials before and after c. 1790—challenge the current understanding of the chemical revolution. Seen from our new perspective, Lavoisier and his collaborators reaped the rewards of a century. In so doing, they introduced reforms of concepts, theories, analytical methods, and language. Yet they neither initiated an ontological rupture nor overthrew the existing taxonomic structure of their main objects of inquiry, the chemical substances. Chemists continued to live in largely the same world of objects of inquiry before and after the Lavoisierian reforms. Well into the nineteenth century, in large areas of chemistry, especially plant and animal chemistry, modes of individuating, identifying and classifying substances were similar to artisans' and naturalists' classificatory practices. This began to change in the 1830s with the emergence of the new experimental culture of organic or carbon chemistry. The pure stoichiometric substances produced, individuated, identified and classified in carbon chemistry were embedded in a web of new types of experiments and work on paper with chemical formulae that did not exist outside academic chemistry at the time. However, as material things these novel substances remained potential commodities—a potential that began to be realized some twenty years later with the rise of the synthetic dye industry. There was no move away from perceptible, applicable substances and towards the study of imperceptible chemical composition or molecular structure in nineteenth-century chemistry. The significance of perceptible substances was not transformed into that of mere targets that allowed experimental investigations of molecular structure. Rather, substances remained chemists' predominant objects of inquiry well into the twentieth century, and studies of composition, constitution and molecular structure remained closely tied to studies of the perceptible and applicable dimension of these things.

## Workshops and Edited Book Project

(*Ursula Klein* in Collaboration with *Emma Spary*, Department of History and Philosophy of Science, Cambridge): *The Making of Materials: Science and Technology in the Early Modern Period*


Emma Spary

This book project, which is based on two workshops that took place in December 2004 and August 2006, brings together the contributions of fourteen well-known scholars from a range of disciplines; they include historians of science and medicine, cultural historians, historians of technology and sociologists of science. Their essays deal with different aspects of the relations between the sciences and the arts and crafts in the production of material substances in the early modern period. Most, perhaps all, of the materials studied in the volume—among them metals, gunpowder, dyestuffs, milk, distilled liqueurs, timber, cosmetics, vegetable remedies—appear as unusually complex "thick things," which challenged the historical actors' collective skills and routine techniques, procured unforeseen effects, and often resisted expressed goals of production and established schemes of understanding. Gunpowder, for example, though apparently made from the same ingredients mixed together in standard ways, did not always produce the same phenomena. Likewise, the outcome of dyestuff production was uncertain and required ongoing quality control, while plant and animal materials such as balsams or milk resisted straightforward identification by eighteenth-century chemical analysts and pharmacists. The science of artisanal experts and the artistic agendas of savants, which investigated materials like these, demand scrutiny of historical actors' practices in the making of materials and their boundaries between practical and learned knowledge.

Given the widespread involvement of academically trained experts in manufacturing output and the involvement of some social groups of artisans in the publication of texts and drawings in the period between 1500 and 1800, the essays collected in our volume suggest that our application of the terms "arts and crafts" (later called "technology") and "natural sciences" must be reconsidered in writing the history of that period. Early modern learned polemics against unlettered, routine and machine-like artisans operating outside scientific institutions have all too often blinded historians to the relations between social space and forms of academic and practical expertise. Further problematizing the issue have been long-standing moral hierarchies among learned elites, which privileged public benefit over personal gain, and nineteenth-century scientistic hierarchies which privileged theory, abstraction and epistemic purity over practice, materiality and the embeddedness of objects in intersecting learned, commercial, and everyday worlds. Such asymmetries continue to color our understandings of the relationship between learning and the arts and crafts, materiality and science, even when we are aware that forms of conceptual knowledge and bodily skills in transforming matter were distributed among social groups in many different ways. In the volume we seek to replace the extant polarization between craftsmen and philosophers in the early modern period with a finer-grained classification of makers and knowers. The studies assembled in the volume address a range of problems. They ask how forms of learned knowledge and bodily skills were involved in the making of materials such as gunpowder, liqueurs, or chemical remedies. They explore the interactions between governments, artisans and academicians in the production of materials, and consider the ways in which the social economy of conceptual knowledge and skills changed between the sixteenth and eighteenth centuries. They investigate the relations between the commodification of nature and materials in the eighteenth century, and the social, material and cognitive networks of scientific and artisanal practices. They show how the scientific expertise and social authority of different makers of materials were mediated by social place, access to print or patronage, wealth, conduct and self-fashioning. By exploring the relations between modes of production and consumption of materials, the essays throw new light on the ways in which changes in production, consumption and commodification affected scientific expertise or social authority over materials.

→ "Professional Knowledge of Practitioners" p. 23

## Further Participants and Activities

Andrew Pickering was a visiting scholar of the group, contributing to the two workshops and the book project *The Making of Materials*.

Maria Rentetzi (post-doctoral fellow and visiting fellow in 2004 and 2005) contributed to the project with a comparative study on radium in the early twentieth century. Comparable to the substances in eighteenth-century chemistry, which were both commodities and scientific objects, radium was widely used in the early twentieth century: as an object of scientific inquiry in chemistry and physics, a source of radiation in medicine, and a component of food, cosmetics and other goods of daily consumption.

Leo Slater was a visiting scholar in the research group and in Department III, working on vaccines in the twentieth-century medical-industrial complex in the U.S.A.

Andrew Sparling contributed as predoctoral fellow to the project with a study on Johann Rudolf Glauber (1604–1670) and alchemical substances in the seventeenth century. Glauber sought to support himself by marketing substances such as *spiritus salis* (hydrochloric acid) and sal mirabile (later Glauber's salt, sodium sulphate), which became applied as chemical remedies from the late seventeenth century onward. At the same time he presented himself as a philosophical alchemist, and thus rhetorically demarcated himself from ordinary craftsmen, *Laboranten* (most of which were distillers), and merchants.

In collaboration with the *Collegium Johann Beckmann*, a working group in the German *Society for the History of Technology*, Ursula Klein organized a workshop entitled

"*Materia technologica*: Rohstoffe in historischer Perspektive," which took place at the *Deutsches Technikmuseum Berlin* in April 2006. A related book entitled *Materia Technologica*, edited by Ursula Klein and Torsten Meyer, will be published in the series *Cottbuser Studien zur Geschichte von Technik, Arbeit und Umwelt,* ed. Günther Bayerl, Münster: Waxmann.

## Project 2

# Technoscience *avant la lettre*

*Ursula Klein, Dana Simmons*


Dana Simmons

Historical studies of the making of materials in the early modern period lend themselves to another historiographical theme: the emergence and historical forms of technoscience. The systematic and stable interconnection of scientific and technological practices and institutions into a "technoscience" is usually considered as the outcome of developments in the twentieth century, with forerunners in the second half of the nineteenth century. In the time period before the late nineteenth century, so the predominant view, there may have been exchanges of knowledge, skill, and instruments between savants experimenting at academic institutions and manufacturing craftsmen and artisans, but this interaction did not result in a sustained interconnection of these two cultures. Traditional history of chemistry has adapted historical accounts of chemistry prior to the emergence of synthetic-dye industry in the second half of the nineteenth century to this predominant general view. Although it has been acknowledged that chemical technology occasionally stimulated developments in eighteenth-century academic chemistry, and vice versa, chemical science and technology prior to the late nineteenth century have largely been studied as two separate domains. By contrast, it is the central thesis of this project, based on previous historical studies, that chemical science and technology were strongly and systematically connected with each other long before the second half of the nineteenth century. The project aims to unravel these interconnections, with a focus on the eighteenth century.

After the first successful steps were taken in the seventeenth century to institutionalize chemistry in academies, medical faculties, botanical gardens, and museums (such as the Ashmolean Museum at Oxford), in the eighteenth century chemistry was an established part of the intellectual world. Eighteenth-century chemists were teachers and professors, authors of learned books and experimental reports, members of academies and scientific societies, and visitors of coffee shops and salons. Yet, they differed markedly from other savants of the time; not only because they spent many hours of the day experimenting in the laboratory, but also because of their diverse technological and commercial activities. Many of the eighteenth-century European chemists were apothecaries, metallurgical officials and consultants, inspectors of manufactories, members of state committees and technological boards, and entrepreneurs. Eighteenth-century chemists working at medical faculties, professional schools and other academic institutions instructed their students about pharmaceutical techniques and various areas of practical, artisanal chemistry. In their laboratories they repeated artisanal operations and analyzed materials produced and applied in the chemical arts and crafts, in the first half of the eighteenth century using almost exclusively instruments shared with assayers, apothecaries and other artisans.

The interconnectedness of chemical science and technology in the eighteenth century did not merely depend on the existence of the hybrid persona of artisan-chemist, occupied with both scientific and technological activities. It was sustained in particular by a shared material culture that spanned from the academic laboratory to the chemical workshop, and comprised material objects of inquiry, instruments and vessels, reagents, techniques and the laboratory. Eighteenth-century chemists shared many of their instruments and vessels with assayers, apothecaries and other artisans. Their smelting and testing furnaces, bellows, crucibles, calcination dishes, and balances overlapped with the instruments used by assayers. The same types of mortars, pestles, filters, vessels, boxes, glass tubes, vials, retorts, alembics, pelicans, receivers, and transmission vessels that academic chemists used in their laboratories were also used in the laboratories of eighteenth-century apothecaries for the making of medicines. There was even correspondance of the size of vessels and instruments used by academic chemists, apothecaries, assayers and distillers. The small-scale trial was intrinsic to assaying, which studied the composition of ores and other minerals to calculate the productiveness of mining and metallurgy. As pharmacy was still a handicraft in the eighteenth century, it also produced remedies on a small scale and for a comparatively small community of local consumers. The distilling of essential oils for the making of perfumes and alcoholic spirits was performed on a small scale too, even though there was enormous modification of distilling apparatus used by commercial distillers.

Unlike the core areas of eighteenth-century experimental philosophy that became transformed into “experimental physics” in the course of the nineteenth century, chemistry was a culture that established specific sites for experimentation and manufacture, the “laboratories.” In the eighteenth century the term “laboratory” referred almost exclusively to distinct rooms where chemical operations (from the point of view of the historical actors) were performed. The Latin word *laborare*, from which “laboratory” is derived and which designated manual work, points to the similarity of these places with workshops. In the eighteenth century “laboratories” were both rooms for experimenting at academic institutions and for chemical manufacture and control in the apothecary trade, assayer’s shops, arsenals, and distilleries. By contrast, in the core areas of experimental philosophy, “physical cabinets” and “physical theaters” were established. As is almost manifest in these latter terms, these institutions served as locations for the collection and exhibition of instruments and for the demonstration of curious experimental effects, rather than as actual places of daily experimental work.

The overlap of the material equipment of eighteenth-century academic chemical laboratories with artisanal laboratories accorded with the fact that academic chemists shared most of their experimental techniques with apothecaries, assayers and distillers. Dissolutions, distillations, evaporations, precipitations, combustions and smelting were types of operations performed by both academic chemists and artisans. As many of the material substances studied in academic chemists's laboratories were bought from merchants and applied in practice by apothecaries and other artisans, the agreement between the material culture of chemical science and chemical technology was quite strong. Work and publications on this theme by Ursula Klein focused on eighteenth-century chemistry, the hybrid persona of the eighteenth-century chemist-artisan (or chemist-technologist) and the shared material culture of chemical science and chemical arts (or chemical technology). See, in particular, Ursula Klein, ed. "Technoscientific Productivity," special issues of *Perspectives on Science* 13 (2005) 2 and 3.

Chemical-pharmaceutical instruments, 17th–19th century (courtesy of the Apothekermuseum, Basel)

Chemical-pharmaceutical instruments, 17th–19th century (courtesy of the Deutsches Apothekermuseum, Heidelberg)

For the work of Dana Simmons who was a postdoctoral fellow both in the Department III and in this Research group, see page 122.

## Project 3

# Historical Styles of Experimentation and Observation: *Historia experimentalis*

*Ursula Klein*

➜ “History and Epistemology of Experimentation” p. 90

Historical studies of materials in the early modern period also shed new light on another prominent theme in the historiography of science: the history of experimentation and observation. Questioning the common view that “experimental philosophy” was the only style of experimentation in the early modern period, they contribute to a historicization of our concept of experimentation.

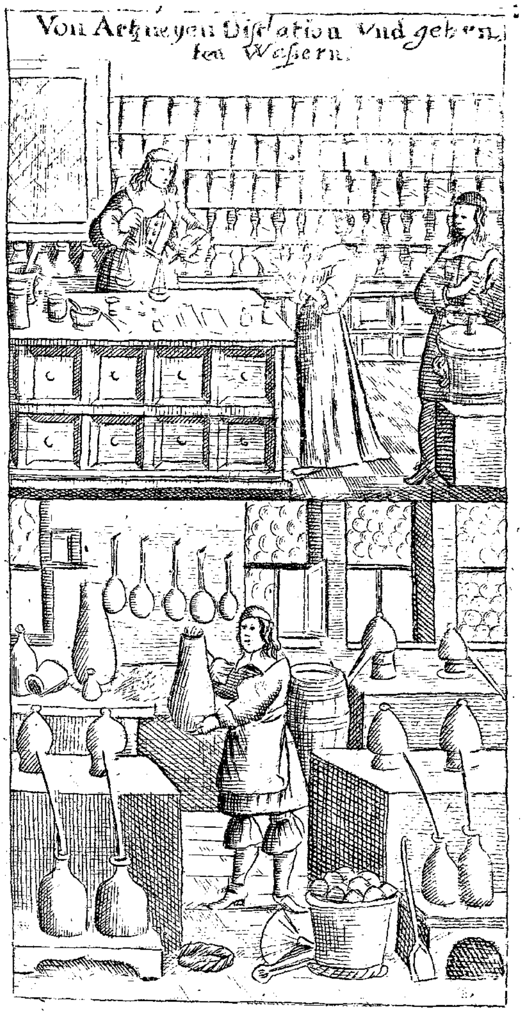
From the late seventeenth century until the early nineteenth century, “experimental history” (*historia experimentalis*) was a collective style of experimentation in addition to “experimental philosophy.” The “experimental history” institutionalized during the seventeenth century was a tradition of experimentation and observation that evolved around the multiplicity of natural and artificial things. Like natural history, experimental history collected, described and ordered facts relating to the perceptible dimension of a great number of different objects. But whereas natural history was concerned with the observation and collection of things “given by nature,” experimental history reported phenomena procured by intervention into nature, both in the arts and crafts and academic laboratories. For example, late seventeenth-century and eighteenth-century chemists’ experimental histories of substances reported phenomena observed at many different places, ranging from households and everyday life to the fields, the workshop and the academic laboratory. Their experimental histories of substances ended with the collection and classification of phenomena, leaving inquiries into their causes to “experimental philosophy.”

An explicit program of an “experimental history” first arose in the early seventeenth century when Francis Bacon (1561–1626) became its most prominent spokesman. Bacon outlined his ideas of an experimental history (*historia experimentalis*) in a text entitled *Preparative towards a natural and experimental history*, which was published in 1620 in the same volume with the *Novum Organo*n. Experimental history in Bacon’s original sense was, first of all, a collection and description of existing factual knowledge developed in the arts and crafts. It was an inventory of artisanal operations and experiments in the broadest sense, which complemented natural history. Robert Boyle (1627–1691), a keen follower of Bacon, also argued that learned men must collect as many facts as possible from craftsmen and merchants. Robert Boyle, in particular, made efforts to demarcate experimental history from its philosophical counterpart, that is, experimental philosophy. For example, in his *Experimental History of Colours* (1664), he asserted that his present work will excite its readers by the delivery of matters of facts, free from any speculation and explanation. He further added remarks about the method and the literary style of experimental history, which served to demarcate it further from experimental philosophy. Experimental history did not require a structured presentation of facts. If the experimenter was not, or not yet, able to create order among the experimental facts and to discover regularities, he could present them as they came to mind and hand, that is, by "declining a methodical way." Furthermore, as experimental history in its most rudimentary stage was a mere collection of phenomena engendered by operations or experiments, the extension of experiments required the greatest "liberty" of action, that is, the experimenter was allowed to add new experiments and thereby collect new facts without knowing where the journey would go. Unlike experimental philosophy, experimental history abstained from reduction, conceptual unity, and inquiry into hidden movements and causes.

Boyle's emphasis on the absence of any speculation and preconceived methods in experimental history, his insistence on the collection of phenomena without any intellectual and methodical constraints, resonated with a broad cultural movement: the *historia* tradition. The *historia* tradition had gained momentum in the Renaissance, when physicians and other learned men revalued the empirical description of objects of nature and of human action vis à vis speculation about causes. As Pomata and Siraisi pointed out recently, "*historia*" offered thorough descriptions of "how things are" without explaining why it was so. It sought to base knowledge on sense perception and aimed at knowledge of particulars without forming an overarching conceptual umbrella. Furthermore, Bacon's and Boyle's insistence on the importance of technical artifacts and artisanal "experiments" for the writing of an experimental history was embedded in another ongoing cultural movement, which revalued the role played by the methods and accomplishments of artisans for the acquisition of natural knowledge. The technological treatises of the fifteenth and sixteenth centuries on architecture, machines, shipbuilding and navigation, military instruments and ballistics, the art of fortification, mining and metallurgy, alchemy, the art of distillation and so on gave voice to this new attitude, which questioned the Scholastic divide between manual labor and theory, nature and art, certain knowledge (*episteme*) and technology (*techne*). Both the *historia* tradition and Baconian experimentalism stabilized experimental history as a collective style of experimentation and contributed to its institutionalization as an acknowledged academic practice.

➜ "History of Scientific Observation" p. 49
➜ "History in Early Modern Europe" p. 50, which concentrated on activities in the historia tradition other than historia experimentalis

Early modern assaying laboratory (courtesy of the Deutsches Museum München)



17th-century officine and laboratory. From B. Schnurr, Vollständiges Kunst-, Haus- und Wunder-Buch. Frankfurt: 1676

Historians of science have discussed Bacon's program of an experimental history mainly in connection with the Royal Society's endeavor of a "history of trades" in the seventeenth century. But this program also had an impact on the encyclopedic ventures of the *Académie Royale des Sciences,* such as the large seventeenth-century project on the history of plants, which also included chemical experiments; *the Descriptions des arts et métiers*; and the more successful *Encyclopédie ou dictionnaire raisonné des sciences, des arts et métiers* by Denis Diderot and Jean D'Alembert (1751–1780); as well as on the plan of the Berlin Society of Sciences between 1718 and 1720 to put together a *Theatrum Machinarum Universitatis*, that is, a precise description of all machines that exist in the world along with depictions. Moreover, the Baconian program of an experimental history also lent intellectual authority to a distinct style of academic experimentation, different from "experimental philosophy," which continued well into the nineteenth century. This latter significance of "experimental history" for an adequate historical understanding of the institutionalization and development of the experimental sciences from the early modern period until the early nineteenth centuries has been ignored almost completely in the existing historical literature.

The distinct style of experimental history can be discerned especially well in the history of chemistry from the late seventeenth century to the early nineteenth century. In the chemistry of this period, "experimental history" meant a collection of phenomena or facts about a great number of particular substances from all possible practical areas, ranging from artisanal sites and everyday life to the academic chemical laboratory. Chemical experimental history was concerned with ways of preparing substances, the perceptible properties of substances, that is, their color, smell, taste, consistency, measurable physical properties, and chemical properties and their practical uses. It meant an extension of objectives of natural history to a laboratory science, which, like the classical domains of natural history—botany, zoology and mineralogy—was concerned with a great multiplicity of things. Its objects of inquiry were not hidden causes and imperceptible entities (such as atoms, forces, the vacuum, electrical fluids and other typical philosophical objects of "experimental philosophy"), but the perceptible dimension of materials and operations. And its goal was not philosophical knowledge, but connoisseurship of materials, their varieties, properties, ways of chemical transformations, and practical uses. Well into the nineteenth century, chemists often performed experiments on a broad variety of different substances, knowing that they would not, or not yet, be able to unravel regularities and general chemical laws, or to improve chemical theories. One day they would study a mineral water from a nearby spring, the next day an iron ore from a new ore deposit, then test the quality of a dyestuff produced in a local manufactory, distill rosemary to reproduce the essential oil of rosemary sold in apothecary's shops, and afterwards study the chemical properties of apothecaries' ordinary ether and compare it with ethers prepared in slightly different ways in their laboratories. Their experiments turned from the study of a material belonging to one class to that of another class, and from the kingdom of minerals to vegetable and to animal substances, and vice versa. Compared to experimental philosophy in the seventeenth and eighteenth centuries, and compared also to the comparatively coherent "experimental systems" in the twentieth-century laboratory sciences, which evolve around one, or one system of, scientific objects and cluster of questions, this style of experimentation may at first glance appear as aimless artisanal tinkering or mere cookery. As it contributes little to heroic historiography, historians of chemistry, too, have obliterated it from systematic historical research. Instead, most historians of chemistry have highlighted episodes of eighteenth-century chemical experimentation in which experiments were more systematically focused on one scientific object and interconnected to a coherent "investigative pathway" (F. L. Holmes). However, the scientific careers of the vast majority of chemists from the seventeenth century until the first decades of the nineteenth century show that, as a rule, chemists' experiments studied a great number of different substances, and often changed from one substance to the other without organizing their experiments into a systematic investigative pathway, directed either "by nature" or conceptual concerns.

Another characteristic feature of the experimental history in eighteenth-century chemistry was the frequent repetition and extension of experiments performed with one particular substance, and the continuous accumulation of factual knowledge about the ways of its preparation, its perceptible properties and practical uses. In the course of the eighteenth century it was especially the testing of chemical properties—such as combustibility, acidity, solubility in various solvents, interaction with reagents—that contributed to the extension and refinement of the experimental histories of substances. "Chemical property" referred to the observable phenomena that were created when a substance was heated or mixed with a reagent. Experimental histories reported such phenomena without seeking to explain them by referring to invisible movements of substance components and chemical affinities. In the second half of the eighteenth century chemists' testing of the chemical properties of substances with a growing number of solvents and reagents led to an enormous increase in the size of experimental histories, sometimes covering dozens of pages for one single substance. At the same time chemists addressed a broader and more diverse audience than in the early eighteenth century, when physicians, students of medicine and pharmaceutical apprentices constituted the majority of practitioners interested in chemistry. New groups of practical men interested in learning chemistry, such as dyers, manufacturers and officials of the state bureaucracy, demanded detailed descriptions and analyses of multifarious artisanal techniques. This development contributed to changes in the presentation of experimental histories, especially in chemical textbooks, in the last decades of the eighteenth century. Chemists then often presented experimental histories of substances in a style of disinterested collection of facts that was disconnected from the practical uses and techniques in the chemical arts. This move was reinforced by the separation of eighteenth-century chemical textbooks into parts on "pure chemistry" and "applied chemistry," with the inclusion of the histories of substances in the part on "pure chemistry" and the descriptions of artisanal techniques and practical uses of materials in the part on "applied chemistry." Nevertheless, the observation, repetition and modification of artisanal operations in the academic chemical laboratory remained an important source for chemists' experimental histories of substances well into the nineteenth century, as can be seen much better in experimental reports than in chemical textbooks. Likewise, observations on visits to mines, foundries, assaying shops, mints, distilleries, dyeing manufactories, workshops of glass makers, chemical factories and so on were a persistent source not only for texts on "applied chemistry" but also for chemists' experimental histories of substances. Furthermore chemists in both the early and late eighteenth century gathered facts for the writing and teaching of experimental history in their own artisanal occupations as apothecaries, mining officials, inspectors of dyeing, porcelain makers, manufacturers of beet sugar and other kinds of chemical entrepreneurship. Eighteenth-century chemists' dual careers as savants and technologists contributed considerably to their experiential knowledge and to the enrichment of their experimental histories.

Two publications on this theme appeared in 2003 and 2005: Ursula Klein. "Experimental History and Herman Boerhaave's Chemistry of Plants." *Studies in History and Philosophy of Biological and Biomedical Sciences* 34 (2003): 533–567. Ursula Klein. "Experiments at the Intersection of Experimental History, Technological Inquiry, and Conceptually Driven Analysis: A Case Study from Early Nineteenth-Century France." *Perspectives on Science* 13 (2005) 1: 1–48.

### Project 4

## Paper Tools

*Ursula Klein*

In continuation of two earlier book projects (Ursula Klein, ed. *Tools and Modes of Representation in the Laboratory Sciences.* Dordrecht: Kluwer, 2001; Ursula Klein. *Experiments, Models, Paper Tools: Cultures of Organic Chemistry in the Nineteenth Century.* Stanford: Stanford University Press, 2003) Ursula Klein has further studied the role played by paper tools (chemical formulae) in the experimental practice and concept formation of nineteenth-century chemistry. These studies have been part of a collaborative, cross-disciplinary project of the Hermann von Helmholtz-Zentrum für Kulturtechnik (Humboldt-Universität zu Berlin) on the productive function of sign systems in science, technology, and art.

Inspection of the paddle wheel after the breakdown of the experimental performance.
Photo: Norbert Gerdes, Oldenburg

# Independent Research Group II

## Experimental History of Science

Director: *H. Otto Sibum*

From the beginning, the objective of the independent research group has been to investigate the *texture of scientific change*. In the last decade historians of science have shifted their attention to look beyond familiar printed sources. Wanting to understand what scientists *did* and not merely what they wrote, historians have drawn their readers attention to the silent representatives of the past in order to understand the hands-on processes by which science is made: instruments, laboratory architecture, personal diaries, lab- and field notebooks, and collections of strange objects. In this endeavor the research group focused especially on the knowing body of the scientist, by combining historical scholarship with the re-working of experimental practice. In particular, embodied knowledge was explored, that is, the historical and epistemological meanings of the experiencing subject in physical investigations of nature. Previous generations of historians had emphasized that remarkable achievements in science were often based on a semi-mystical "tacit" or "personal" knowledge. We were however able to show that this tacit knowledge can usefully be conceptualized as embodied knowledge, a form of knowledge that can be reconstructed by looking at the intersection of actions and structures in specific fields of cultural production.

Hence we have taken up the challenge represented by the long-standing divide between epistemology and practice, and sought to break with traditional concepts of disembodied knowledge. At the heart of this conception of embodied knowledge lies the unity of experience of the actors involved in productive work. Knowledge governs but does not determine practice; and practices, as they are enacted, may constitute a source of new information and open prior knowledge to reproduction or transformation—with implications for subsequent practices. Hence this is not merely about shifting historians' interest from the 'software' of science to its 'hardware;' we have attempted to go beyond the time-honored divide between 'thinking' and 'doing'—a dichotomy often reproduced in the very process of being questioned—by putting forward a conceptualization of practices as 'knowledge in action.' Experimental as well as theoretical techniques are hence to be understood as human performances of specialized work involved in generating knowledge.

Within this conceptual framework, members of the group have pursued research projects covering two important historical periods of cultural and scientific change. The first one explores hitherto unrecognized practical knowledge traditions and their impact on the formation of science during the mid-18th until the mid-19th century. The second focuses on the changing experiential basis of science in the period between 1870 and 1920. The project leader H. Otto Sibum has finished his long-term project on experimental thermodynamics and the embodiment of knowledge in the age of precision. Together with David Aubin and Charlotte Bigg he also completed a research project on observatories and observatory techniques in the nineteenth century (D. Aubin, C. Bigg, H. O. Sibum (eds.) *The Heavens on Earth. Observatory Techniques in the Nineteenth Century*, forthcoming with Duke University Press. The current members of the research group are pursuing the following research projects.

→ “History of Scientific Observation” p. 49

Project

# Working Knowledge and Science 1780–1870

This project aims at investigating an historical period in which modern science was coming into existence, a period critical for the investigation of the fruitful and reciprocal interactions between science and other forms of knowledge. It spans the mid 18th until the mid 19th century—a time of major cultural transformations. It is the age of Enlightenment with its ideal of promoting "useful knowledge." As historians have come to realize the close ties between epistemology and praxis, so too their terminology for this time has come under question. Economic historians who once spoke of the industrial revolution can now be heard referring to the "Industrial Enlightenment." Historians of science, once comfortable with the "second scientific revolution" (understood as the quantification of the Baconian sciences) followed by the conception of the rise of "a quantifying spirit" now stress the importance of the geographical dimension of knowledge creation in the Enlightenment period.

What does it mean to work in a scientific workplace, to labor in a scientific laboratory? What kind of knowledge is situated in these specialized performances of work? These are the questions at the heart of the project. They are questions that take on new meaning in the period just discussed. Originally the terms episteme, scientia, scienza, science, Wissenschaft meant knowledge or skill in general. It is only over time that they became specialized terms to denote a more certain and authoritative form of knowledge than "ordinary knowledge." Moreover this linguistic divide is often mirrored by a social distinction between those who work with their heads and those who work with their hands. It even contributed to a cultural distinction between West European lands (and former colonies) that have modern science and those that do not. Most recent historical scholarship emphasizing the geographical dimension of Enlightenment science has already started to provide several case studies that open these workshops of knowledge creation.

At its broadest, this project studies the changing character and status of work in this process of the formation of the exact sciences in the century after 1750, emphasizing the changing forms of intellectual work in relation to physical labor. In this way, the field, the workshop, the cabinet, the laboratory can all be studied as sites of "knowledgeable labor." On this basis we seek to reconstitute past practitioners' knowledge of different kinds of experimental work regardless of disciplinary boundaries. Furthermore a detailed reconstruction of practices of exchange between these individuals and collectives provides further insights into a hitherto unknown web of practitioners' knowledge. The large-scale mapping of such knowledge traditions and their interactions allows us to study in detail the historical and epistemological conditions of the emergence of scientific knowledge in this period. To this project several researchers are contributing.

→ "Professional Knowledge of Practitioners" p. 23

Anna Märker

**Anna Märker** (Postdoctoral Fellow, Cornell University, U.S.A.) joined the group in 2005 with a project on the notion of "useful knowledge" and the emergence of modern science, 1750–1850. The aim of the project is to investigate conceptual changes concerning the notion of utility in science around 1800 in order to illuminate how these changes were part of the development of modern scientific practice and its cultural, institutional and social context. At the current stage, the project is based on two case studies located in the eighteenth and early nineteenth century. The first case study is an analysis of Kant's *Natural History and Theory of the Heavens* in the context of contemporary natural historical approaches; it is used to analyze the relationship between natural philosophy and natural history with regard to the concept of utility. A second case study concerns the transfer of the production of anatomical models from Florence to Napoleonic France in the context of institutional and conceptual changes regarding the role of natural science for the state. The studies address questions such as: What is the (implicit or explicit) understanding of utility that underlies a particular claim to the usefulness of natural knowledge? Which actors assert, or contest, such claims? For whom is knowledge about nature considered to be useful, and in what way? What is the mutual influence between this notion of utility, scientific institutions and knowledge-making practices? How do changing concepts of utility thus relate to the emergence of new regimes of knowledge production?

Simon Werrett

**Simon Werrett** (Visiting Scholar, Washington University, Seattle, U.S.A.) continued research on his project, Fireworks and Natural Philosophy in Early Modern Europe, exploring the history of changing interactions and definitions of art and science seen from the perspective of the history of pyrotechny and its evolving relationship with the sciences in early modern Europe. Taking a comparative perspective in several national contexts, primarily England, France, and Russia, Werrett traces the history of the art of making and performing fireworks for war and display from the late fifteenth century to the era of Europe's Napoleonic wars, when fireworks were transformed

The British Jubilee: Being an exact Representation of ye Fire Works in ye Green Park at St. James (London, 1749) engraving. Anonymous, A collection of cuttings from newspapers, advertisements, playbills, etc., formed by Fillinham. Bound in eight volumes (c. 1700–1860), Vol. 5, f. 47v. The British Library, London into commercial spectacles similar to those still witnessed today. In the interim, fireworks occupied an intriguingly ambiguous and shifting position in classifications of knowledge and practice, whereby a great variety of opinions and activities identified and allied pyrotechny with different arts and sciences. Werrett's research, which he expects to appear as a monograph in 2007–08, traces these different positions and relates them to the social, cultural, and historical contexts within which fireworks were performed, examining contests among groups including gunners, mathematicians, men of letters, natural philosophers, architects and poets, as they sought to define the nature of pyrotechny and claim authority over fireworks performances. By following the history of fireworks, Werrett addresses a long-standing theme in the history of science, concerning the debts of early modern science to the skills and practices of artisanry, traditionally a question explored in relation to the 'Scientific Revolution' of the 16th and 17th centuries. The case of pyrotechny, examined here over a longer period and in several different locations, demonstrates the complexity, contestedness, and enduring interactivity of artisanry and science, a reciprocal relationship not restricted to the Scientific Revolution, but one continuing and evolving into the nineteenth century. By recovering the pyrotechnician's skills and practical knowledge, Werrett shows the many ways fireworks offered resources for transformations in natural knowledge-making, and how in turn the sciences shaped the history of pyrotechnics in a great variety of ways over several centuries. These interactions, contests, transfers and alliances are set in historical context, and offer fresh insight into the shape and meaning of science as it related to the arts in early modern Europe.

Annik Pietsch

***Annik Pietsch*** (Research Scholar) is continuing her investigations on innovations in painting techniques in Germany 1750–1850 with the aim to solve a puzzle well-known amongst art historians and conservation scientists: despite the improvement of scientific knowledge about light, color and matter in the 1800s, the period saw little by little the disappearance of well-established painting practices, a process historical usually referred to as the "Verfall der Malerkunst" (degeneration of the art of painting). Contrary to the common understanding that this degeneration took shape because of a lack of quality in materials and techniques, or a lack of artistic quality according to aesthetic criteria, Pietsch argues that painting techniques are part of a much broader transformation occurring in a complex network of diverging knowledge traditions concerned with light and color. Her analysis of this process is based on a careful investigation of individual works of art as manufactured objects. Painting techniques serve here as a nexus where scientific, philosophical, aesthetic and technical discourses intersect; and where practices, concepts and materials of the different knowledge networks are exchanged. This study concentrates on developments between 1750 and 1850 in the Prussian capital, Berlin, with

"Bildnis des Philosophen Hegel, 1831 gemalt von Prof. Jak. Schlesinger, Generalrestaurator der königl. Museen zu Berlin". Staatliche Museen zu Berlin a focus on the events around 1820-1830. Three characteristic paintings were chosen: *Die Erfindung der Malere*i by Eduard Daege (1805–1883), *Bildnis des Philosophen Hegel* by Jakob Schlesinger (1792–1855) and *Die Schlucht bei Amalfi* by Carl Blechen (1798–1840). These three paintings, each belonging to a different type of painting genre (history, portrait and landscape painting), were all produced around 1830 by painters of the same generation. Each is an exemplar of one of the main painting techniques of the time and thus can serve as a key starting point to describe the broader historical development of these specific technologies.

***Larry Stewart*** (Visiting Scholar, University of Saskatchewan, Canada) is engaged in research into the development of sites of experimentation during the early industrial revolution. His focus has been on chemists and their laboratories, from private sites in country homes, to commercial enterprises associated with manufacturing, such as those of James Watt and Josiah Wedgwood, to academic laboratories, and including the experimental efforts of small philosophical societies. Much of the research involves the international trade in instruments including Italy, France and the Netherlands as well as Britain between 1760 and 1820. This work has led to a collaboration with the University of Saskatchewan, Canada.


M. Norton Wise

***M. Norton Wise*** (Visiting Scholar, University of California at Los Angeles, U.S.A.) continued his work on the book project on bourgeois Berlin and laboratory science. Laboratory science, in the modern sense of laboratory teaching and research carried on at universities, only came into existence in the first half of the 19th century. The development occurred in all European countries but with quite different historical trajectories. This book takes up the issue for Prussia: How did laboratories enter the universities, and especially the University of Berlin, where they had been excluded under the neo-humanist vision of higher learning, which separated the pursuit of the ideal from that of the real, or the Humboldtian nurturing of the mind from material interests? It seeks its answers rather broadly, in the historical dynamics of the industrializing military state of Prussia and the middle-class citizens who saw themselves and their capacities as the motors of the future.

What classical languages were to the Gymnasia and Universities, mathematics and science were to a variety of new schools established to modernize the military (Kriegsschule and Vereinigte Artillerie- und Ingenieurschule) and to promote modern industry and civil engineering (Gewerbeinstitut and Bauschule). Teaching laboratories first appeared in these state-supported institutions. One crucial feature of their organization was that they drew many of their teachers of mathematics and science from among young university faculty, and it was these same people who carried the interests of the technical schools back into their university teaching. Especially notable for this book are the teachers—Magnus, Dove, Mitscherlich, Dirichlet—of the circle of ambitious young men who founded the Physikalische Gesellschaft zu Berlin in 1845, including Emil du Bois-Reymond, Werner Siemens, and Hermann Helmholtz. This group provides the concrete basis for exploring the rich interaction of artistic interests, classical values, mathematical methods, and precision instruments that shaped the science that came to be called modern. It was a science that emerged at the crossroads of intellectual and technological culture and it is just this cultural crossroads that the book seeks to illuminate.

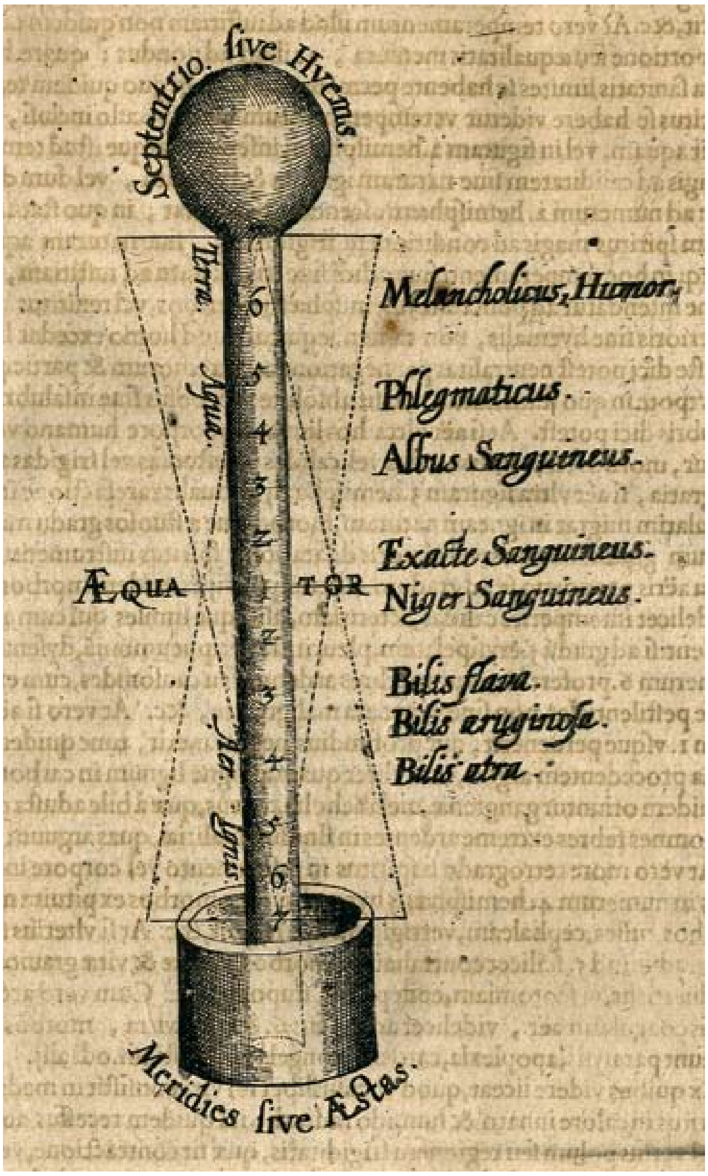
Frédéric Graber

***Frédéric Graber*** (Postdoctoral Fellow, Centre Alexandre Koyré, France) investigates leveling practices in 18th and 19th century France and Germany. At the turn of the 19th century a new hope emerged for some French engineers that large scale field-data gathering would help shift one of the most typical activities of engineering from the field into the cabinet: leveling, the measure of the difference of level between two points. There was a diversity of leveling practices. Leveling was used by very different kinds of people, ranging from specialized engineers, who understood leveling as a high-precision measurement and gave it a central place (both technically and socially) in their project-making activities, to completely unskilled users, mostly interested in draining or diverting water for agricultural or industrial purposes. Leveling was also used by surveyors or topographers as one tool for establishing the altitude of given points in the landscape: these practitioners did not usually seek (at least until 1830) the same degree of precision as that required by civil engineers, wanting instead to give a global account of the relief, using techniques such as the naked eye or hypsometry. (Some scientists around 1800, dealing mainly with natural history, like Humboldt or Ramond, had a similar approach to heights, seeking to relate the presence of minerals or plants to a given geographic situation.) The surveyors adopted a global approach but only measured the altitude of a very small number of points they deemed significant, while the civil engineers' approach was very local (they usually measured only a strip of land) but with a great number of very close points (between 50 and 200 meters, compared to usually several kilometers for topographers.) The dream of a global knowledge of leveling was, in a way, a coming together of these two traditions. General-leveling were interesting both for topographers (especially military topographers) and civil-engineers, but these two groups had completely diverging expectations of what was relevant data and appropriate precision. Such large scale leveling could only be undertaken by state institutions, and studying the first attempts at launching such projects after 1800 is revealing of the conceptions of the competing groups of state engineers involved. Only a few, medium-sized, projects were carried out before the second half of the 19th century. By 1860, general-leveling was considered as an essential task for most European nations.

The aim of this project, transformations of decision-making tools, is to understand and place this hope in a more general picture of the transformations of leveling techniques between 1750 and 1870 (when all European countries launched their respective national projects of general-leveling), and especially in a general transformation in public works decision-making circa 1800, and the emergence of new requirements, such as explicit alternatives and comparisons.

Arianna Borrelli

**Arianna Borrelli** (Postdoctoral Fellow) has begun a project on heat and cold in observation and explanation in early modern and modern times. Ever since antiquity, heat and cold have been used both as descriptive and as explanatory concepts for a very large—at times unlimited—range of phenomena. Today as in the past, both stand very close to everyday experience, yet only one of them, heat, has found entry into modern science. Probing the history of heat and cold offers a possibility of investigating practices of experimenting and theorizing before they either became confined to their present roles as components of modern science or were completely excluded from it. At present, the investigation concentrates on two areas of interest, both concerning the boundary between observation and description and its role in defining phenomena and their explanations. One focuses on the early modern period, broadly circumscribed as the weatherglass and its observers in early seventeenth-century Europe. The second project concentrates on thermometer readings and equilibrium around 1800. By then thermometers had become an important tool for investigating the nature of heat, and thermometrical readings had emerged explicitly as a key factor in defining thermal equilibrium between physical systems. Joseph Black is usually considered the first to have underscored this connection. Around the same time, Johann Heinrich Lambert proposed to regard thermometers as measuring the force of heat which caused systems to reach equilibrium. One aim of this project is to collect and analyze the various viewpoints on this subject expressed by natural philosophers and craftsmen in the last decades of the 18th century and beyond, i. e. before the formulation of the second law of thermodynamics and the definition of absolute temperature based on it.



Robert Fludd, Integrum morborum mysterium: sive medicinae catholicae tomi primi tractatus secundus ... (Frankfurt: Wolfgang Hofmann, 1631), p. 53. The scale of the weatherglass is here related to the four elements (left) and to the five humors characterizing man's temperament (right). Image reproduced from: UB der HU zu Berlin; Robert Fludd, Integrum morborum mysterium: sive medicinae catholicae tomi primi tractatus secundus (Frankfurt, 1631); Med Nat 35; p. 53.

***John Tresch*** (Visiting Scholar, Chicago University, U.S.A.) worked on the relationship between humans, technology and nature in the early machine age. His book project *Mechanical Romanticism: Techniques of Transformation in French Science and Culture, 1815–1851* examines reactions to the new machines of the Industrial Revolution and their impact on understandings of nature and society. The interrelations among various fluids and forces harnessed by new technologies (light, heat, steam, electricity, magnetism, spiritual power) suggested a dynamic and protean cosmos susceptible in many ways to human modification; research into these fluids and forces often involved an image of science in which investigator's moral aesthetics, and political qualities were engaged. Further, the discourses surrounding these entities were often characterized by uncanny mixtures of the organic and the mechanical. The project shows how the definitive sciences and technologies of the start of "the machine age" implied rather different relations between humans, technology, and nature than our current categories might lead us to expect.

Project

# Science and the Changing Senses of Reality Circa 1900

The turn of the twentieth century is usually described as a crucial moment in the history of the physical sciences. One especially striking issue is the increasing number of techniques for investigating microphysical objects including x-rays, electrons, atoms, ions, molecules, and bacteria. Sophisticated instruments and apparatus were often described as extensions of the human senses and opened novel experiential spaces for scientists. These rare scientific experiences also challenged theory, putting new demands on those seeking to unify science. They induced among scientists an increasing reflexivity about their tools and methods and reshaped their sense of reality.

→ "Reorganizing Knowledge in Developed Science" p. 28

In this new world of scientific experience, physical scientists were confronted anew with an old debate concerning the relation between knowing and doing, and theory and experiment, which had accompanied the empirical sciences since their beginnings. According to the theoretical physicist Felix Auerbach, the various techniques applied by physicists to make the invisible visible were no longer mere practices of observation (such as those used in botany, astronomy etc): modern physics was, methodologically speaking, an engineering activity. "X-rays were not discovered by Röntgen," he concluded, "but in the first place invented in his laboratory." In the early 20th century the term invention became an apt description of the working techniques applied in the modern physical sciences. But it equally mattered in mathematics, engineering and the arts. Hence this project focuses on a number of such techniques and their interrelations to understand how they changed scientists' practice and their sense of reality. Further we investigate the role played by this change of experiential space in the reflexive turn in the sciences, formulated in the early writings of Ludwik Fleck, Michael Polanyi, and Gaston Bachelard.

Several fellows contributed to this research project within the research group or as participants in an international conference convened by the research director in November 2004.


Charlotte Bigg

***Charlotte Bigg*** (Research Scholar) is investigating "Brownian Motion and Microphysical reality circa 1900". The irruption of new microscales on scientific research agendas arguably contributed to a profound transformation in scientific practices and social organization in the early twentieth century. The case for this argument will be made for the physical sciences on the basis of a study of Brownian motion research in the 1900s. She investigates the investigations carried out by a handful of physicists and chemists in these years, most notably Jean Perrin.

Brownian motion, the perpetual and irregular motion of particles suspended in a solution, had long been known but until then little noticed. In the 1900s it came to encapsulate the fundamental issues at stake in early-twentieth century physical sciences: the nature and structure of matter, the relationship between statistical mechanics, kinetic theory and thermodynamics, and more broadly the validity of hypotheses and mechanical models in science.


Microphotograph of the height distribution of resin granules suspended in water. Brownian motion is responsible for the statistical stability of this distribution, which is comparable to the height distribution of gaz molecules in the atmosphere. This photograph was exhibited in the museum Jean Perrin helped create, the Palais de la Découverte, in the section dedicated to his own researches on Brownian motion. Photothèque Palais de la Découverte

Specifically, she examines how Perrin and Einstein deployed theory and experiment to produce for the first time 'visual' evidence of the existence of atoms and of the statistical nature of the second law of thermodynamics, e. g. how they developed methods to make sense of the behavior of floating submicroscopic particles and connect it with broader issues in the physical sciences. Close attention is paid to scientists' intricate interweaving of chemical and physical theories to account for the individual and collective behavior of particles, the significance of his application of Boltzmann's statistical mechanics for this purpose, and its implications for assessing the commensurability of the macro- and microscopic dimensions and for the development of thermodynamics. She investigates how the Brownian motion of submicroscopic particles was experimentally turned into 'visual' evidence of atoms, most notably through the use of the ultramicroscope, a new instrument enabling the visualization of particles below theoretical resolution (though not of atoms). And how Perrin in particular worked to make the molecular dimension intelligible by extending the domain of application of different theories into the molecular or macroscopic realms (e. g. extension of the kinetic theory of gases to suspended particles). In this respect, a comparison may be made with the simultaneous discovery of the syphilis bacillus using the ultramicroscope, and how microbiologists negotiated similar issues of scale shifting. Through a close analysis of the relatively circumscribed field of Brownian motion research, the momentous scientific, disciplinary and social stakes at play in this period and the profound transformation of the physical sciences are investigated.

David Aubin

***David Aubin*** (Visiting Scholar, Université Pierre et Marie Curie, Paris, France) investigates Bénard Cells and Self-Organization. Henri Bénard was a French physicist who performed experiments on fluids for a Collège de France physics course given by Marcel Brillouin at the turn of the century. Bénard was among the first to study the behavior of a thin layer of liquid, about a millimeter in depth, when heated from below, the upper surface being in contact with air at a lower temperature. Experimenting with liquids of different viscosity, he observed in all cases the formation of a striking pattern of hexagonal cells. In 1916, Lord Rayleigh provided a mathematical explanation for the onset of instability in such a convective system. In his 1900 article, Bénard used a variety of means to visualize the structures he wanted to exhibit. They ranged from material substances he added to the liquid to optical contrivances such as lighting and the design of special photographic setups. His papers were abundantly illustrated with sketches and photographic clichés. Starting in 1904, he produced a series of films, which he used to analyze the phenomenon and showed at the Easter, 1914, meeting of the French Physical Society. The observation of self-organization in physical systems provided a formidable boost to those who wished to explain the phenomena of life in mechanical terms (D'Arcy Thomson). Bénard himself thought that physicists ought to be more ambitious in their pretension to understand nature, and this spontaneous emergence of organization struck him as having potentially important applications for the life sciences.

David Bloor

***David Bloor*** (Visiting Scholar, University of Edinburgh, U.K.) is doing research on the history of aerodynamics which focuses on a scientific controversy about the reasons why an aircraft wing generates lift. British and German experts disagreed over this question up until the 1920s. Following the work of Kutta and Prandtl, German experts developed the circulation theory, while British workers, guided by the achievement of Rayleigh, initially developed the theory of discontinuous flow. The aim of the book is to explain this systematic divergence in approach. It is significant that the British entrusted their aeronautical research to a group dominated by Cambridge-trained mathematical physicists, while the German effort was led by mathematically sophisticated engineers and applied mathematicians from the Technische Hochschulen. One factor of great significance is the different attitudes of the two national groups to ideal fluid theory. German engineers treated it as a useful tool, while the British treated it as a physically false theory and tried to develop a systematic account of viscous flow.

***Andrew Warwick*** (Visiting Scholar, Imperial College, London, U.K.) focused on the development of x-ray technology within a medical context in the decade after 1896. Taking Hamburg as an example, he showed that, contrary to received accounts, the initial wave of enthusiasm for x-rays as a medical tool was followed by a backlash in which x-rays were widely regarded as of little or no medical value. This disillusionment was generated by the new rays failing to fulfill the unrealistic expectations raised in medical minds by the notion of a new ray which allowed one to see inside the living human body much as an autopsy revealed the contents of a dead one. In practice, x-ray technology was too difficult for most doctors to use reliably, and even good pictures required considerable skill to integrate into medical diagnosis and treatment. The research aims at investigating the notion of entrepreneurship in Germany circa 1900 in the form of the small group of doctors, technologists, engineers, and physicists who gradually and painstakingly made x-rays an indispensable tool to medicine.


Suman Seth

***Suman Seth*** (Postdoctoral Fellow, Princeton University, U.S.A.) studies the practices of theoretical physics in Germany between 1890 and 1930. He has characterized aspects of the development of the field in terms of a dichotomy between two "kinds" of theoretical physics, distinguished by their methods, world-views, discourse, and techniques: what has been termed "the physics of principles," and what he terms "the physics of problems." The physics of principles, which had as its most prominent proponents Poincaré, Planck, Einstein, and Bohr, can be seen as the most significant continuation of—and response to—fin-de-siècle debates about the foundations of physics, offering in place of any particular materialist ontology a physics based on generalized principles. The physics of problems was both newer, beginning essentially with Sommerfeld's move to Munich in 1906, and largely avoided the questions of foundations, Sommerfeld once quipping to Einstein that "I can only further the engineering of the quantum [die Technik der Quanten]. You would have to make its philosophy." Others had the same impression, the Oxford physicist Frederick Lindemann writing to Einstein in 1933 that "I have the impression that anyone trained by Sommerfeld is the sort of man who can work out a problem and get an answer, which is what we really need at Oxford, rather than the more abstract type who would spend his time disputing with the philosophers." Where Planck, for example, promoted a practice of theoretical physics devoted to abstract, de-anthropomorphized, de-historicized, "pure" principles, Sommerfeld focused on specific problems, drawing these from a variety of sources, including six years spent teaching at an engineering college (Technische Hochschule), often emphasizing questions of economic or technological benefit. And where the physics of principles provided (indeed, provides) the dominant discourse of the new discipline, Sommerfeld's newer theoretical physics would supply the lion's share of its younger practitioners, training three generations of students, at least eight Nobel prize winners amongst them. Sommerfeld's many students adopted his way of seeing the physical world and his and their analytic practices represent a dominant strand in what the field came to be. Only by studying these two "kinds" of theoretical physics together can one begin to understand the formative years of a discipline that, to many, signified the pinnacle of scientific achievement for the twentieth century.


Richard Staley

**Richard Staley** (Visiting Scholar, University of Wisconsin-Madison, U.S.A.) seeks to deliver new perspectives on the material, conceptual and disciplinary foundations of physics in the period from 1870 to the 1920s. A primary focus (and the subject of a book manuscript in preparation) is a new account of the multiple lines of investigation—theoretical, experimental and instrumental—which coalesced, diverged and intersected anew to produce not only the history of relativity we currently recognize, but a more complex, contingent and involved story with a cast of unfamiliar characters and new themes. Why did Michelson and Morley never complete the ether-drift experiment as planned in 1887? How is the history of the screw relevant to the analysis of space and time in 1905? Who invented "classical" physics? There are several important methodological underpinnings to the project. The first is to follow the multiple threads of many actors with different trajectories and interests, as they work overlapping but not parallel lines of investigation. This means exploring the research concerns of the originator of the ether-drift experiment, and what he made of his experiment—a new instrument—rather than inquiring solely about crucial experiments or the use theorists made of the Michelson-Morley experiment. It means investigating the material culture of measuring space and time, in experimentalists' work to track the motion of electrons on minute photographic plates in 1905. It means exploring the formulation of concepts of "classical physics" in the work of a host of theorists after the arrival of Planck's quanta and Einstein's relativity in 1900 and 1905.

**Robert M. Brain** (Visiting Scholar, University of British Columbia, Canada) studied the "Pulse of Modernism: Experimental Physiology and Artistic Avant-Garde ca. 1900." Modernism is a term often used to express the changing sense of reality in turn-of-the-century arts and sciences. Very often modernism is invoked to join industrial modernity and the vanguard arts without a firm causal link between them. This paper demonstrates the indispensable role of the experimental physiology laboratory as the middle term between industrial procedures and artistic practices and ideologies. Proponents of physiological recording devices sponsored a skepticism towards traditional and consensual languages, methods, and institutions in favor of a new modernist focus on essential and formalized protocols, and a "Kantian" reflexion on the conditions of possibility of scientific knowledge. From the physiology laboratory these familiar modernist standards migrated into the ateliers of painters, poets, musicians, and architects. He describes several different pathways between labs and modernist artistic movements in both France and Germany, showing how experimental physiology was pressed into the service of a different kind of modernism in each country. French artists used physiological aesthetics to transform representational techniques but left the traditional categories of artistic spectatorship unchanged. German vanguards, by contract, joined physiology with home-grown notions of empathy (*Einfühlung*) and expression to create an aesthetics of the body-turned-inside-out, a relation of projection and recovery that would heal the ills of the division of labor in society. With the attempts of the Bauhaus and others to produce industrial artworks of everyday life, the transitive relation of industrialism, physiology, and artistic modernism came full circle.

The art historian ***Bettina Gockel*** (Visiting Scholar, Universität Tübingen, Germany) investigated Paul Klee's practice of picture making as a tool for making the invisible visible. The artistic materials, also marginal and every day materials, as well as line and color should become tools of pure invention while preserving an autonomous status of their own. The aim was to make an invisible reality visible that is to say to give it a specific presence. The investigation of the relation of Klee's concept of art "to make the invisible visible" with the "building" of his persona or self was studied on the foil of the problematic and finally unsatisfactory representational concept of the self-portrait, a genre which became incompatible with Klees radical questioning of traditional modes of representation after 1919.

***Gadi Algazi*** (Visiting Scholar, Tel Aviv University, Israel) started his project on "Making Invisible Movement Visible: Norbert Elias's Motion Pictures." The challenge to the conventional sense of reality after 1900 was not limited to the natural sciences alone. It also had implications for the study of society, culture and history. This project focuses on some neglected attempts to rethink the social and cultural sciences under the impact of the emergence of new technologies and medial configurations. Its point of departure is a reconstruction of the methodological assumptions underlying Norbert Elias's early work.
How to make invisible movement visible? This was the question Norbert Elias was struggling with, as he spent his days in Parisian libraries in 1935, reading through existing cultural histories and putting together the elements of what was to become his major work, *The Process of Civilization*. No problem seems more difficult for historians than conceptualizing, portraying and explaining change; it is also the most common task they encounter. But in Elias's case, the problem posed itself in a particular, challenging way.

How can you reconstruct a historical process spanning hundreds of years, one that lies well beyond the reach of conventional history? It is through this long-term historical process, Elias assumes, that actors with a particular psychological make-up, capable of coping with the requirements of modern societies, have been formed. If practitioners of micro-history would later insist that some processes can only become visible under a microscope, Elias claims that structural changes in the standards of behavior or the organization of personality can only be perceived once we go beyond the usual time-frame of conventional historical reconstruction. One needs a telescope, if you will, in order to discern a process of gradual structural change spanning hundreds of years. But how should one put together a body of evidence in order to make plausible the claim that this change indeed took place? And given such a corpus of evidence, how should it be manipulated in order to make that long-term, structured change—what Elias calls 'process' in the strict sense—visible?

The workshop "New Paths of Physical Knowledge. Science and the Changing Sense of Reality circa 1900" was held at the Max Planck Institute for the History of Science in November 11–14, 2004. The book will be published with Chicago University Press. Titles of papers and authors are given below in alphabetical order.

**Science and the Changing Senses of Reality Circa 1900,** H. Otto Sibum, editor

- *Auerbach's Dilemma—Introductory Essay*
- *Making Invisible Movement Visible: Norbert Elias's Motion Pictures* Gadi Algazi (Tel Aviv University)
- *Seeing Structure, Structuring Sight: Bénard's Cells and the Visualization of Self-Organization* David Aubin, (Université Marie at Pierre Curie, Paris)
- *Brownian Motion and Microphysical Reality c. 1900* Charlotte Bigg (MPIWG)
- *Sichtbarmachung, Common Sense and Construction in Fluid Mechanics: The Cases of Hele-Shaw and Ludwig Prandtl* David Bloor (University of Edinburgh)
- *The Pulse of Modernism: Experimental Physiology and Artistic Avant-Garde ca. 1900* Robert M. Brain (University of British Columbia, Vancouver)
- *From Phenomenology to Phenomenotechnique: The Role of Early-Twentieth-Century Physics in Gaston Bachelard's Philosophy* Cristina Chimisso (Open University, Milton Keynes)
- *Picture Making As a Tool for "Making the Invisible Visible" Paul Klee's Art and Persona* Bettina Gockel (Universität Tübingen)
- *"Pushing the Limits of Understanding": Debating Primitivism in Cultural Science, 1900–1930* Doris Kaufmann (Universität Bremen)
- *Ways of Seeing: Ludwik Fleck and Polish Debates on Perception of Reality, 1890–1947* Ilana Löwy (INSERM, Paris)
- *Inventing the 'World of the Infinitely Little': Physics and Instruments of Psychical Research in Britain circa 1900* Richard Noakes (Cambridge University)
- *The Question of Modernism: Herriman, Hilbert, Brouwer and Others* Herbert Mehrtens (TU Braunschweig)
- *Heredity and its Entities around 1900* Hans-Jörg Rheinberger (MPIWG)
- *Engineering the Quantum. Arnold Sommerfeld and the Older Quantum Theory, 1915–1925* Suman Seth (Cornell University, Ithaca)
- *World Views and Physicist's Experience of Disciplinary Change: On the Co-Creation of Classical and Modern Physics* Richard Staley (University of Wisconsin, Madison)
- *Rethinking the Early History of X-rays* Andrew Warwick (Imperial College, London)

## Further Projects

### By Means of Performance: Visualizing Science at Work (H. O. Sibum)

Historians of science have repeatedly argued that the concrete process of working in a laboratory or workshop can usually only be recovered with difficulty and incompletely from historical texts and illustrations. The performance of an historical experiment such as James Joule's paddle wheel experiment to determine the mechanical equivalent of heat has proved to be a fruitful method of uncovering essential experimental techniques and forms of knowledge. In the course of this long-term project several replicas of historical experiments have been built and the respective reenactments closely studied. This project is now taken a step further by exploring the potential encapsulated in filming the reenactments of past experiments in order to provide a new visual archive for historians of science. In collaboration with Wolfgang Engels and Falk Riess from the Universität Oldenburg and the film maker Roland Steiner (Oldenburg) the group is currently filming the various stages of the process of getting C.T.R. Wilson's cloud chamber experiment to work.

### Practicing Theoretical Physics: Making Sense of Felix Auerbach's Notebooks (H. O. Sibum)

With the assistance of the Library the note books (approx. 11,000 pages) of the Jena theoretical physicist Felix Auerbach have been digitalized. These short hand writings of the years 1872–1920 are currently transcribed and will provide a rich resource to study the heterogeneous practices of theorizing in physics in this important developmental stage in physics.

## Research Grants Received

Charlotte Bigg "Brownian Motion and Microphysical reality circa 1900" position subsidized by the Deutsche Forschungsgemeinschaft (DFG), 2–3 years.

## Collaborations

Workshop "Intellectual Work as Labor" co-organized with M. Norton Wise and held at the University of California Los Angeles (UCLA), February 2004.

With Larry Stewart (University of Saskatchewan, Canada), Scientific instrument trade in the 18th century (especially electricity and magnetism).

## Planned Workshop

"Practical Knowledge Traditions and Scientific Change, 1750–1870" to be held at the Max Planck Institute for the History of Science, Berlin, February 2007.