

## What Kind of Science Is Experimental Physics?

H. Otto Sibum

This year's essay series highlights the benefits that scientists, science, and technology have brought to society throughout history.

In 1923, the German theoretical physicist Felix Auerbach told his readers that experimental physicists, unlike botanists or geologists, do not observe nature but rather artificially create physical phenomena in their laboratories. He made what would today be regarded as a contentious claim (1):

X-rays are not a 'natural phenomenon', until Röntgen there weren't such, they have been invented by him (this expression is more appropriate than the conventional 'discovered'); and in case it turns out that there will be such rays in nature, this does not change the issue essentially.

Reflections like this on the artificial technological character of experiment—or, more precisely, the kind of scientific experience gained through the use of human devices—is not just an important expression of Auerbach's time. It is an integral part of a long historical debate, going back at least to the 17th century, about the epistemological status of experiment and experience. In this essay, I concentrate on the mid-18th to the early 20th century, a time period in which a "third man" was sought to bridge the divide between theorists and practitioners, between science and the mechanical arts. The consequent emergence of a new scientific persona—the experimentalist—was coupled to the establishment of experimental physics as an academic discipline.

Since the early modern period, scholarly opinions on "the art of experiment" ranged from denying that it had any epistemological value to the 19th-century conviction that this form of inquiry was the only way to make sense of natural causes. A key issue in these controversies was that the physical manipulation of objects was seen

as not belonging to the scholarly tradition, in which a clear distinction between doing and knowing still predominated. In 1764, the philosopher Christian Wolff argued (2):

In such circumstances, a third man would be needed, who could in himself unite science and art, in order to correct the *theorists'* infirmities and to combat the prejudice of the lovers of the arts, as if they could be therein complete without the *theory*, and leave [theory] to the idle heads good-for-nothing in the world.... Hence ... [the engineer] compared himself to a bat, tolerated among neither birds nor quadrupeds, and he complained that he was hated by the practitioners of art as well as despised by the *theorists*, for he wanted by his nature to be celebrated as a remarkable man by both, and to share fame in the learned world with the latter and happiness at court with the former.

In establishing experimental physics within academia, experimentalists were experiencing the advantages and disadvantages of the third man's position. Like bats, they were difficult to classify. Did their studies of nature, practiced with head and hand, lead to a specific form of knowledge? And did this knowledge qualify as science? How one answered this question depended on one's stance toward the implicit distinction made in those days between experimental knowledge and science, or knowledge in general and scientific knowledge in particular. Furthermore, the dominant understanding of



**Reproduction of a historical experiment from the 18th century.** The light phenomena produced through mechanical friction in a vacuum tube were considered a model of the Aurora Borealis.

scientific knowledge as universal, autonomous, and permanent was intimately linked with the hegemony of the written text in the scholars' form of life. Hence, from the mid-18th century onward, several generations of experimental natural philosophers were required to free the art of experiment from its epistemological stigma and to position their knowledge within academia.

The main challenge to traditional text-based scholarship was that experimentalists' had to develop and study instruments to investigate nature's effects.

The new fields of electricity and magnetism within experimental physics were particularly challenging, because nearly all phenomena connected with these fields were observable only with the assistance of instruments or apparatus. Artificially created illuminations in an electrified vacuum tube were regarded as models of the Aurora Borealis. But experimenters did not only equate artificially created phenomena with macroscopic phenomena. In the late 18th century, the Italian physicist Alessandro Volta succeeded in detecting and explaining microphysical phenomena. He constructed a model of the electric fish, today known as the first electric battery, which for the first time demonstrated the existence of an electric current. At the end of the 18th century, different knowledge claims based on experiences made in those artificially created local settings often led to controversies about the true meaning and scope of these experiences.

Despite the immense practical achievements in creating "new physical truth," this conflict persisted into the 19th century. Artisans, merchants, engineers, instrument makers, and scholars participated in a complex historical process of molding the physical sciences based on experimentation. Artisanal knowledge became essential for the experimental sciences, but this expert knowledge resided outside of academia. The material interests of the state in promoting industry and the military enabled experimentalists to pursue their research and finally forced traditional academia to establish scientific laboratories (3).

The term "Handwerksgelehrte," coined in Germany in the second half of the 19th century, captures the amalgamation of the experimentalists movement with the traditional academic elite. What had previously been regarded as separate knowledge traditions—experimentalists and bookish scholars—now merged into a distinct community of experimental scientists in which ways of acting and ways of knowing had equal epistemological status (4). By the end of the 19th century, lab-

H. Otto Sibum is at the Max Planck Institute for the History of Science, Wilhelmstrasse 44, 10117 Berlin, Germany. E-mail: sibum@mpiwh-berlin.mpg.de

oratories had been established in most universities in Europe and North America.

The teaching of physics also changed during this time. Chairs for experimental physics were set up, and a new scientific methodology emerged. Hermann von Helmholtz and James Clerk Maxwell promoted an understanding of induction that stressed the similarities between the intellectual work of the experimental physicist and that of the artist. Both continuously reminded their audiences that experimental physics differed from traditional scholarship. Maxwell followed his general conviction “that the facts are things which must be felt, they cannot be learned from any description of them” (5). Similarly, Helmholtz told the Naturforscherversammlung in Innsbruck in 1869 (6):

Besides the kind of knowledge that books and lectures provide, the researcher in the natural sciences needs the kind of personal acquaintance that only rich, attentive sensory experience can give him. His senses must be sharpened.... His hand must be exercised that it can easily perform the work of a blacksmith, locksmith, joiner, draftsman, or violinist.

This plea represents the gradual change in the epistemological status of sensuous experience in science. Helmholtz, Maxwell, and others placed sensuous experience center stage in the process of generating scientific knowledge and of bridging the divide between theorists and practitioners.

And yet, reflections about the epistemological status of experimental physics in general and sensuous experience in particular continued. Not only the new Handwerksgelehrte, but even laypersons forcefully argued for a mediation between knowing and doing, theory and experience. The German tanner Joseph Dietzgen, for example, announced in 1869 that the third man’s problem had not been fully resolved (7). To him, the tension resulted from a conflict between two philosophical traditions about the sources of knowledge: the idealist regards the source of knowledge in reason only, the materialist in the sensually perceived world. But he saw a way out of this contradiction (7):

The mediation of this contradiction requires the insight that both sources of knowledge are intimately connected with each other.... Therefore even the lowest art of experiment which acts on the basis of experienced rules, is only gradually different from that scientific practice which is based on mere theoretical principles.

By the end of the 19th century, the increasing number of techniques to investigate microphysical objects, such as x-rays and electrons, changed the experiential basis of physics and evoked various reflections about these sources of knowledge. Particularly the artificial technological character of experimental physics was discussed (1):

Experimental physics does not—as the term already suggests—practice observation of nature like other natural sciences, it deploys artificial experiments which are performed just for a specific purpose. Strictly speaking, physics with regard to its method is not a natural science like astronomy, geology, botany, etc.; it does not deal with natural phenomena but artificial phenomena produced by intentional acts of the researcher; in this sense we can speak of physics as a technical science.

By 1900, more than 90% of German physicists practiced precisely this technical science. But the physics community was still not speaking with one voice, and several different stances about the epistemological status of experiment and sensuous experience in generating knowledge continued to exist. The experimental physicist Otto Wiener suggested that instrument-based physical research should be regarded as an evolutionary process

of the extension of the human senses. Generalizations were derived from sensuous experience. Consequently, elements of theory were to be understood as “condensed experience.”

Auerbach took a very similar stance in describing the practice of theoretical physics: for him, the source of scientific knowledge was always experience, the

latter not to be regarded as the test of a theory but as the materials to build up the theory. The implied claim—he argued—that theoretical physics constructs its general fundament from experience might make it appear as if physicists are arguing in a circle. How could one derive the facts of experience from a general schema and at the same time gain this schema by orientating one’s self toward experience?

To persuade his audience, he refers to the most striking invention of 19th century electrical engineering: the dynamo. First built by Siemens, it starts to produce current immediately when turned by hand, because a trace of magnetism inherent in iron produces weak electric currents, which feed the same machine. In a similar way, theoretical physicists want to gain as much knowledge about nature as possible from a mini-

mum of experience. Of course with some practice they could build theoretical physics directly from the condensed experience stored in the mind, with the foresight that a retrospective check against experience will not contradict the theoretical claim; but if contradictions occur, they would have to restructure their abstract building or eventually replace it by another one (8).

Auerbach distinguished this practice of theorizing from another kind of theoretical physics, which promotes the idea that the general can be derived exclusively from the researcher’s mind [(8), p. 2]:

They construct an ideal world, declare their satisfaction, if the real world matches the ideal. But in case of contradictions these theorists would go that far and declare the real world as false because it does not match with the ideal.

In doing so, he clearly commented on a tendency among some theoretical physicists, who held that experience and reason would remain divided in two separate domains (9):

Experience remains, of course, the sole criterion of physical utility of a mathematical construction. But the creative principle resides in mathematics. In a certain sense, therefore, I hold it true that pure thought can grasp reality, as the ancients dreamed.

By the turn of the 20th century, the art of experiment had been developed to the most powerful art of knowing within science. In Germany, experimental physicists regarded the artificial technological character of experimentation as the extension of the human senses, opening up new realms of experience. This changing experiential basis even induced an increasing self-reflexivity in physics, which shaped the formation of different types of theoretical physics.

## References and Notes

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