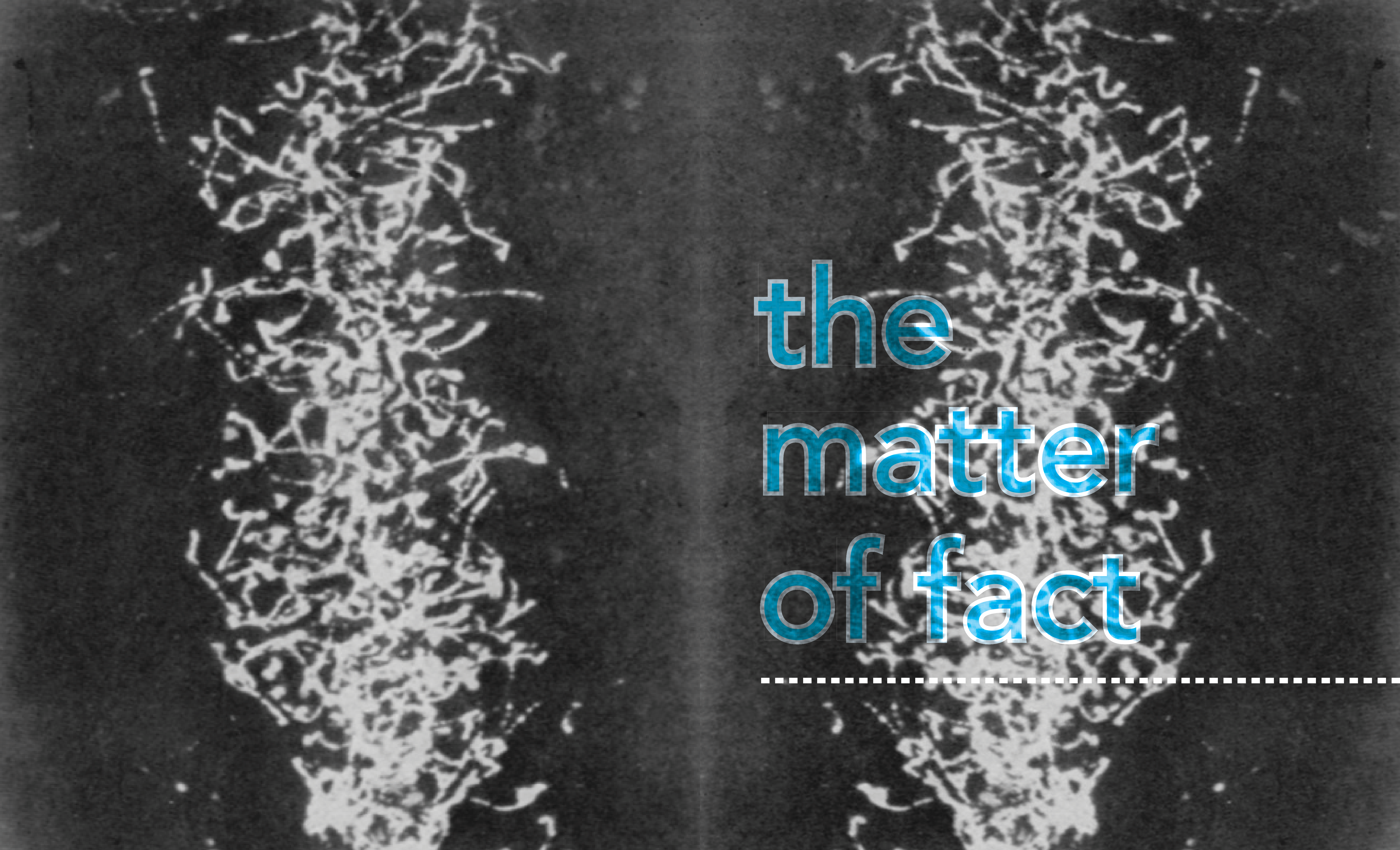

the matter of fact

The Matter of Fact

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an indication that cathode rays possessed an intrinsic electrical charge. Nearly all televisions and computer monitors produced in the twentieth century functioned on this basic principle.

The nature of the cathode ray was a great mystery to late-nineteenth-century scientists. William Crookes believed it to be a fourth state of matter, a form more pure and essential than the common gas, liquid, or solid. His interest in cathode rays coincided with his study and practice of Spiritualism, an immensely popular religious movement in which trained "mediums" attempted to contact the spirits of the dead in trance-like séances. Cathode rays, or "radiant matter" in the language of Crookes' theory, thus tapped in to the public's fascination as well. His papers and lectures were printed by popular presses in Great Britain and the United States. The cathode-ray tube was perhaps most alluring for its colorful, ethereal luminescence, unlike any other form of artificial light in use at the time.

The modern term for the cathode ray, the electron, was coined in the 1890s. Initially, an electron referred to the smallest electric charge found in nature, a quantity that appeared frequently in chemistry. To explain the origin of this quantity, physicists invoked the luminiferous ether, a hypothetical fluid that transmitted light waves in the same way that sound waves travel through air. The prevailing theories supposed that the electron was either a spinning vortex or a vibration of ethereal fluid.

In 1897 J. J. Thomson, the long-time director of the Cavendish Laboratory of Physics at Cambridge University, proposed instead that the electron was a particle of matter with measurable properties like mass and momentum. A cathode ray, he claimed, was a stream of electrons that caused fluorescence when it interacted with other matter. From experiments conducted with an instrument similar to this Crookes tube, he determined some physical properties of the electron, such as the ratio of its mass to its electric charge. Thomson's interpretation was immediately controversial but gained sufficient influence over the next ten years to earn him the 1906 Nobel Prize in Physics.

Cathode-ray tubes were among the most successful and ubiquitous consumer technologies of the twentieth century. Since the 1930s, at least a billion CRTs have been manufactured and sold as components of television and computer displays. Flat-panel display technologies have since displaced the CRT from the marketplace, and disposing of obsolete devices poses a formidable environmental challenge. The average American household has two unused cathode-ray tube devices in storage, most of which will be legally classified as hazardous waste due to high concentrations of lead. As part of a national environmental initiative, Massachusetts mandated the recycling of discarded CRTs in 2000.

Introduction

Jimena Canales

While the word "fact" comes from the Latin *factum*, a noun derived from facere, which means to do or to make, this exhibit explores why in modern usage this term often conveys the opposite: facts are not made but they are "out there". What is the relation between scientific facts and the instruments that are used to produce them? What is a fact?

"The Matter of Fact" analyzes important facts of nature and the instruments associated with the discovery, invention or maintenance of facts. We look at how scholars have dealt with questions of fact in the past and how they can still provide us with tools for thinking about them. Some famous facts, and some famous arguments for or against them, serve as the backdrop for each of the original contributions to the exhibit.

Fact: Heat cannot flow from a cold object to a hot one.

The Second Law of Thermodynamics can be stated in many, different ways. It is used to explain why "ice melts" or why "sandcastles do not arise spontaneously". Because of this law, "time is irreversible" and, if broken, the world would look as if a film were being run backwards. This law gives us reason to believe that "there are no perpetual motion machines" and asks that we stop the millenary, quixotic search for them. It holds because of how molecules move. If we place in a box fast-moving hot molecules on the left side and slow-moving cold molecules in the right side, the hot ones will transfer some of their energy to the cold ones, and eventually the temperature will equalize. But what if we place a door dividing the box into two halves, and open it when a cold molecule approaches the door from the right side and shut it when a hot molecule approaches it from the left side? The temperature on left would increase while the one on the right would decrease, violating the second law of thermodynamics. Nineteenth-century scientists posited "a finite being" that could control this door. It would eventually be named "Maxwell's Demon". Before assenting to this fact of nature, they argued, we must first ask if demons, such as Maxwell's, exist.

William Thomson, "The Sorting Demon of Maxwell," *Proceedings of the Royal Institution* (1879-1881).

Fact: Life cannot be restored to a dead man.

Can life be restored to a dead man? David Hume in his famous *Enquiry Concerning Human Understanding* (1748) says that it cannot. Almost a century later the computing pioneer Charles Babagge held a different view. Yes, life could be restored to a dead man. To explain how this would be possible he used the example of an early computer, which he called a Calculating Engine, that could do a series of mathematical calculations. This computer could also be programmed so that at certain moments there could be exceptions to mathematical rules. For example, while most of the time it would give the mathematically correct answer, at other times it could give an entirely different result. Worldly facts, Babagge analogized, could be compared to those given by this computer. While most of the time both the world and the computer would give a predictable result (such as 2+2=4), there was no reason to believe that these rules could not be at times changed (such as restoring life to a dead man). This naughty computer, Babagge argued, "is more consistent with the attributes of the Deity" than one that did not allow for facts to be, once in a while, predictably unpredictable.

David Hume, "Of Miracles." In *An Enquiry Concerning Human Understanding* (1748).
Charles Babbage, *Ninth Bridgewater Treatise* (1837).

Fact: Water boils at 100 degrees Celsius.

Almost all thermometers show that water boils at 100 degrees Celsius (or its equivalent of 212 degrees Fahrenheit). But what happens if you mix equal amounts of freezing water (0 degrees) and boiling water (100 degrees)? If the "capacity of water for receiving heat, continues permanent at all temperatures between freezing and boiling points" then we can assume that a thermometer should read 50 degrees. Yet different thermometers give different values: while mercury thermometers generally give 50 degrees, alcohol ones give approximately 44, and water ones can give as little as 26. Does this mean that the mercury thermometer is the most accurate? Or does it mean that the real temperature of the mixture is not necessarily "halfway" between freezing and boiling?

Adair Crawford, *Experiment and Observations on Animal Heat, and the Inflammation of Combustible Bodies* (1788).
Hasok Chang, *Inventing temperature: Measurement and Scientific Progress* (2004).

Fact: Dr. Livingstone was found by Mr. Stanley.

We all know how Mr. Stanley found Dr. Livingstone in the town of Ujiji on the shores of Lake Tanganyika on November 10, 1871, greeting him with the famous phrase: "Dr. Livingstone, I presume." But how did people first become convinced of this fact? First, from newspapers "that behaved as they generally do." And the newspapers? From a telegram. And the telegraphic clerks? From their belief that "the electricity behaved in the cable exactly as it behaves in the laboratory." And Mr. Stanley? Through Dr. Livingstone's handwriting and the "curious rule by which an ordinary man's handwriting may be recognized as having persistent characteristics even at different periods of his life." The discovery of Dr. Livingstone in the middle of Africa depended on a number of local and practical judgments which observers trusted. Were these judgments justified because nature acted according to predictable and uniform laws? Or did nature appear to be predictable and uniform because these local practices worked?

Simon Schaffer, "Metrology, Metrification and Victorian Values." In *Victorian Science in Context* (1997).
William Kingdon Clifford, *Lectures and Essays* (1879).

Fact: On 5 May 1961 Alan Shepard was the first American to travel to outer space.

Was this the first time an American traveled to space? In one sense it was. In another sense, he had already been there many other times, and monkeys before him for hundreds of others. The famous astronaut had been "there" repeatedly in a rocket simulator. For Shepard, and for observers on the ground, there was almost no discernible difference between the simulator and the real rocket. The differences were so slight that Shepard remained cool throughout the whole "trip." So in one sense, this flight was just the "nth + 1" rehearsal following the "nth" trip on the flight simulator.

Bruno Latour, *Science in Action: How to Follow Scientists and Engineers through Society* (1987).

Fact: 25X25=625

How do we know that 25 times 25 equals 625? We can take 25 boxes and we can put 25 beads in them. We can then start with the first box and count all beads, continuing on to the second box, until we reach the last box and the last bead. Most likely our result may not be 625: perhaps we lost a bead at one point, lost our concentration at another and missed a couple numbers in between. Perhaps we can use paper and pencil. Write 25 over 25 and a short line below them, multiply 5 by 5, write a number two of slightly lower size over the highest number 2, and write the number 5 below the line. Repeat all the multiplication operations you learned in school. Perhaps you may get 625, perhaps you may not. Even better: type these numbers into a calculator, press "enter", and read the number off the screen. Compare these methods against each other. Why are some considered to be better than others? Is it because 25X25=625 reflects the real laws of nature? Or do we privilege certain methods and technologies because they give us comparable, routine, reliable, widespread and fast results?

Ludwig Wittgenstein, *Remarks on the Foundations of Mathematics* (1959).
Andrew Warwick, "The Laboratory of Theory or What's Exact about the Exact Sciences." In *The Values of Precision* (1995).

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that corrupts the fidelity of a number as it travels between input and output. It is no longer clear that there is a "true" numerical value that can be approached through calculation if numbers are always understood as mere estimations.

Interestingly, while the history of the slide rule's development might discredit the alleged veracity of its calculations, it also instructs us that facts do not need to be thrown away when they are no longer understood as "true." The history of the slide rule is one that is characterized overwhelmingly by an emphasis on utility. Logarithms, the logarithmic scale, and Thacher's Calculating Instrument were all invented to achieve particular ends, and much of modern industry and engineering has relied upon their powers of calculation, despite the increasing numerical uncertainty that these technologies produce. While Thacher views his instrument as a solution to the increasing demands for "more exact calculations," history suggests that there might be value in simply producing ***more*** calculations.

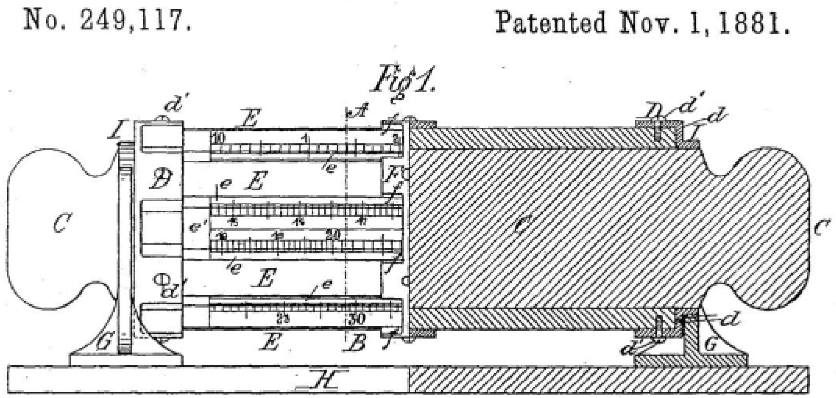
Crookes Tube

Dan Volmar

This replica of a Crookes tube was used in Harvard classrooms circa 1940. An example of an early cathode-ray tube or CRT, the British physicist and chemist Sir William Crookes performed experiments and public demonstrations with this apparatus in the 1870s and 1880s. So prolific was his work that his name became associated with the instrument among English-speaking scientists.

By pumping air out of the tube and connecting the two metal plates to a battery, Crookes could create a brilliant fluorescent glow on the glass opposite from the negative plate or cathode. The cross-shaped metal plate is the anode. During a demonstration, the anode would cast a cross-shaped shadow on the fluorescing glass. This was experimental proof that a radiation emanated from the cathode and that it traveled in a straight line like a ray of light, prompting the term cathode ray. The beam could be deflected by a magnet, the stability of a number and its ability to claim any truth as a calculated fact both become dubious propositions.

A slide rule is, by definition, a device that allows for two scales to be moved alongside each other in parallel, such that the values on its scales can be graphically added or subtracted. While a slide rule could ostensibly make use of arithmetic scales, Thacher's Calculating Instrument, and all those that perform its same operations, employs logarithmic scales to transform graphic addition and subtraction into the functions of multiplication, division, squares, and square roots. The slide rule's dependence on the logarithm as a calculating technology is reflected historically in the proximity of its invention to the Scottish mathematician John Napier's invention of the logarithm in 1614.



Although traditional mathematical education promotes understanding the logarithm as a naturalized entity, Napier invented the logarithm as a mathematical shorthand to represent a specific yet necessarily contingent *relationship* between two numbers, designed intently to simplify the caculations required by seventeenth century navigation and astronomical practices. The logarithm, a mathematical tecnology that is purely analytic, with no numeric or material referent, can only *estimate* a numerical value as an ouput. The logarithmic scale, a graphic materialization of the logarithmic relationship that is the operative mechanism of the slide rule, encodes the logarithm's distortions of estimation, as well as introduces a whole host of additional distortions as the compass used in its construction can never draw a circle as perfect as what is given in an equation, and the marks it makes to tick off divisions can never have no thickness. Thus as a tool for calculation, the slide rule is plagued by an inherent problematic of translation from empirical to analytic and back

The Velocity of the World's Fastest Thing

Mara Block

> *The New York Times*, 1939: *"What is believed to be the most accurate speedometer in the world, which automatically measures the speed of light, fastest thing in the universe... was announced today at Harvard University."*

Anderson's experiment has been received by the scientific community and the media as a revolutionary approach to determining the velocity of the world's fastest thing. But what does it mean to call this value a fact? The 19th century physicist James Clerk Maxwell believed that scientific facts reveal an infallible truth about the nature of the universe. Is the structure of science really this simple? **I, for one, do not believe it possible to consider the meaning of this fact apart from the goals, the expectations, the socio-economic situation, and the agreed upon standards of the community which establishes it.** The 20th century physicist Max Plank offers an attractive challenge in his argument that we can be most certain about the facts "we experience with our own body." **But particularly in relation to light, I'm not sure the meaning of *experience* is any clearer than the meaning of fact.**

On the one hand, the only things we can see are things from which light bounces and reflects into our eyes. **But the nature of light is so bizarre that it needs to be conceptualized differently from everything else.** An experience of light will not result in judgments like "the stove is hot," "this apple is red," or "that pinch hurts." My preference is for a nuanced view of experience such as that of C.S. Peirce (founder of American pragmatism) who argued that value permeates all experience. Similarly, American philosopher W.V.O. Quine argued that science is not reducible to immediate experience.

> *Life magazine, 1939: "Dr. Wilmer C. Anderson of Harvard University, completed the first machine to measure light's speed automatically, with far greater exactitude than any previous machine."*

Many influential thinkers (e.g. Aristotle, Descartes, and Kepler) thought the speed of light was infinite. Sixty years after Galileo's failed attempt to settle this debate, Danish astronomer Ole Rømer was the first to determine a finite value after he noted that less time was required for light to travel shorter distances in his observations of Jupiter and its moon, Io. Two hundred years later, mirrors were introduced into velocity of light experiments. The experiments of Fizeau, Foucault, and Michelson used mirrors (and various rotating wheels) to create pulses of light which were eventually directed at the observer. Anderson's experiment was deemed "revolutionary" because he claimed that it eliminated the need for both a large distance and a human observer. Using a photoelectric cell in place of a human observer, Anderson directed a beam of light through a Kerr cell (glass bodied cell with nickel electrodes filled with nitrobenzene) which split the beam in order to create a pulse—some of the original beam hit a half-silvered mirror and was immediately focused on the photoelectric cell, while the remainder was reflected between three mirrors before finally being focused on this cell. Anderson did not need this beam of light to travel more than forty meters in order to determine his final value of $299{,}764 \pm 12 \frac{\text{km}}{\text{sec}}$.

> *Time magazine, 1939: "Physicist Wilmer C. Anderson who, on the basis of his experiments so far, believes he has reduced the margin of error in measuring light's enormous speed to two and one-half miles per second. When his program of measurements is completed, he expects to have the most accurate figure ever obtained for the velocity of the universe's fastest thing."*

According to the theory of special relativity, the speed of light is a constant that is the same for any observer anywhere in the universe. This has been increasingly called into question over the last ten years by **varying speed of light theories which suggest that c may not be a true constant but one that varies over cosmic periods of time.** The question remains open as to whether the complex philosophical nature of this fact coupled with its historical narrative will decisively challenge the received view of its infallibility.

More Exact Calculations:

Thacher's Calculating Instrument and the Transposition of Mathematical Facts

Stephanie Tuerk

Thacher's Calculating Instrument was, in 1881, the first slide rule to receive a US patent. While Thacher's instrument performed the same operations of multiplication, division, squares, and square roots as slide rules have done since their invention circa 1630, its inventor, Edwin Thacher, a civil engineer from Pennsylvania, heralds his instrument as an improvement on the traditional, flat linear or circular slide rules that preceded it, which, he claims, had become "unfitted for the more exact calculations of the engineer, architect, and actuary" necessitated by modern sciences, technologies, and the desires they produced.

By making use of the surface area of the instrument's cylindrical form, dividing a linear scale into forty lengths that were then printed in parallel, Thacher incorporated thirty feet of logarithmic scale into an eighteen inch long instrument, at a time when the most prevalent slide rule types typically offered between five and twenty inches of scale. The condensation of what would have been an unwieldy and impractical slide rule into a new, manageable form produced a desktop device that could calculate with newfound precision, as so many more divisions could be made along its extended logarithmic scale. Whereas previous slide rules could produce calculations with two, or more rarely three significant figures, Thacher's slide rule calculated to the fourth, and often fifth significant figure. Thus in his patent, Thacher declares that "the purposes of my invention are to increase the length and accuracy of such scales without increasing the length of the rule."

Thacher's elision of greater precision with increased accuracy relies on an assumption that numbers are immutable entities that, no matter how they are manipulated by various technologies of calculation, will result in facts that are necessarily "true." That is to say, in order to believe that the result of a calculation is accurate, one must compare it to some conception of a "true" value of the calculation that exists prior to and independently of the calculation just performed. Yet if one traces a numerical input as it passes through the various physical, graphic, and mathematical innovations that constitute the calculating mechanism of a slide rule, emission from objects for short wavelength but failed to give the correct spectrum at longer wavelengths. Whilst the Rayleigh-Jeans law appeared to fit with experimental data for longer wavelengths and higher temperatures but broke down for smaller values of wavelength and lower temperatures. Hence the wave theory of the time could be used to predict the behaviour on either side of the peak, but could not predict a limiting value for the peak itself. It predicted the peak to be infinitely high, which common sense tells us could never be the case. This problem is what is known as the "ultraviolet catastrophe".

So what did Planck do? Many textbooks tell us that Planck merely merged these two formulae together and miraculously generated a formula that was an accurate representation of the distribution curve. However, this is not what happened. The Rayleigh-Jeans formula is based on equipartition theory, a theory whereby the temperature of a system in thermal equilibrium is related to its average energy. Planck failed to ever believe that equipartition theory was fundamental. For this reason, Planck never regarded the Raleigh-Jeans equation as important and never used it in his work. Furthermore, Planck did not agree with Wien's derivation of his formula. He could not accept Wein's law as "fact".

In 1897 Boltzmann proposed that the second law of thermodynamics needed to be viewed as a statistical law rather than as an absolute fact of nature. This was a concept Planck struggled to accept. After finally finding a formula that precisely fit the experimental distribution, by what he claimed was "an inspired guess", Planck tried every theory he could think of to explain the formula he had found. By 1900 he had exhausted every possible theory other than statistical theory. Planck was not convinced by the statistical argument but resolved himself to the fact that the theory behind the black body radiation had to be found "whatever the consequences." Reluctantly, Planck found that the statistical interpretation of the second law did yield the desired results.

Planck did not realize the consequences of his results when they were established in 1900. In fact, he was reluctant to even publish since the results corroborated a view of the second law that he only begrudgingly accepted. The real historical facts tell us that, despite the account given in textbooks, the ultraviolet catastrophe was not even partly responsible for the introduction of Planck's Law.

Cagniard de la Tour's Siren:

Helmholtz and the Facts of Music

Lisa Crystal

What, if any, is the relationship between science and beauty? A provocative question, to be sure, but also a vague one. Does it ask about the beauty of science? Or else the science of beauty? Perhaps both? If it is the former - the beauty of science – that is at issue, the question concerns the aesthetic appeal of scientific theories. If it is the latter, the science of beauty, it asks about the scientific facts and laws believed to underlie aesthetic experience. The two intersect when scientists bring an aesthetic sensibility to their accounts of beautiful things. The history of acoustics, and in particular the search for laws that govern musical harmony, provides many rich examples of this type of intersection.

On the Sensations of Tone (1863), by German physicist and physiologist Hermann von Helmholtz, is a foundational work in the science of musical theory. Does Helmholtz bring an aesthetic sensibility to this study? Throughout, Helmholtz describes experiments conducted with carefully designed acoustical instruments that he used to corroborate, explain, and further scientific understanding of music. If there is an aesthetic ideal to be found in Helmhotz's acoustical science, perhaps it partially lies with the universality of the basic facts of music, facts that can be demonstrated using simple instruments such as the siren of Cagniard de La Tour.

This siren, given its name in 1819 because of its ability to 'sing' under water, consists of two parallel circular discs, each bearing a ring of equally spaced holes. The bottom disc is fixed to a brass cylinder attached to a set of bellows; the top disc is free to move. A constant stream of air is forced up from the bellows setting the upper disc in motion. When the holes in the two discs line up, air passes through; when they do not line up, the air is blocked. In this manner, periodic puffs of air are produced. The movable disc is attached to a screw that controls a set of dials at the top of the instrument. From these dials, the frequency of rotation can be read off – a frequency which, when multiplied by the number of holes in the discs, gives the frequency of the pulses.

When engaged, Cagniard de la Tour's siren emits a loud, self-sustained tone of known frequency. Helmholtz used this siren to establish several 'facts' about music that were not yet taken for granted. Among these facts was the distinction between noise and musical tones – the idea that the latter originate from vibrations of fixed periodicity and the former from chaotic pulses of air. Also, the siren corroborated the notion that, for musical tones, the frequency of vibration is proportional to the pitch. The siren demonstrated these facts, which Helmholtz describes as resulting "immediately from experiments with the siren."

Having established these basic facts of music, Helmholtz explains how he used the siren, along with a few other simple instruments, to experiment with consonance, dissonance, beats, harmony, partial tones, and combinational tones. He combined these researches with those involving the physiology of the ear, providing reasons for why we hear the pitches, tonal qualities, beats, and harmonies that we do, and why some are pleasing to the ear and others are not.

With Helmholtz we enter a scientific-musical world that involves physical sensation, theoretical explanation, and mechanical demonstration. In this world, the facts of musical harmony are self-evident to all those in possession of functional hearing organs and standardized instruments such as the siren. Helmholtz brings an aesthetic ideal – the universal demonstrability of scientific facts and laws – to bear on his scientific explanation of the experience of beautiful sounds.

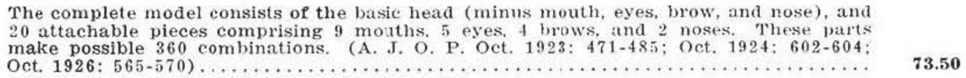
Ritchie's Apparatus and the Ultraviolet Catastrophe

Jo Reeve

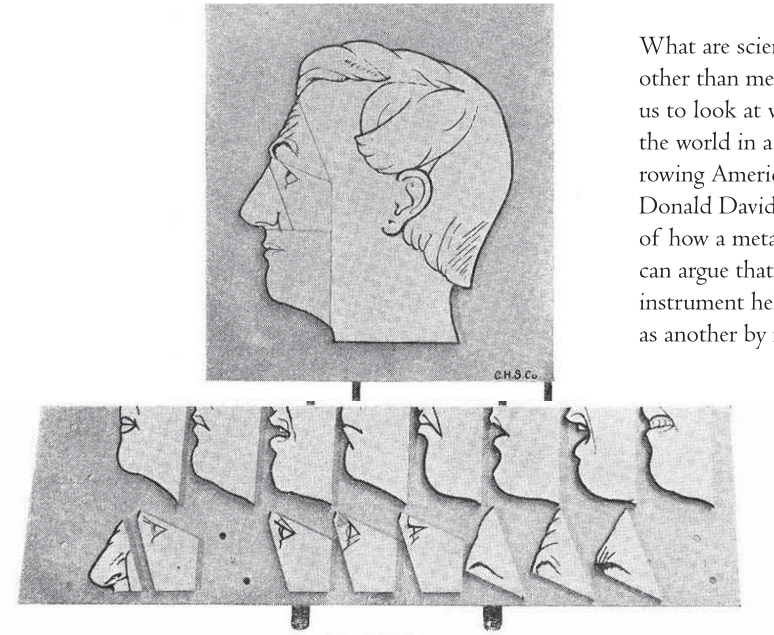
It is a generally acknowledged fact that in 1900 the German physicist Max Planck (1858-1947) produced a paper that changed the way the physics world thought about the second law of thermodynamics. It was in this paper that Planck quantized radiation. Or was it? Is the story really as simple as most textbooks make it out to be? Did the partial failure of the Wien law and the Rayleigh-Jeans law really lead to the ultraviolet catastrophe, and did this actually cause Planck to spontaneously develop the idea of quanta of energy and adopt a statistical view of the second law? Whilst such idealised tales, delivered in most textbooks, make for pleasant reading, the real story is not so straightforward.

From the middle of the 19th century, physicists studied the properties of a "black body." This investigation intensified in 1859 when the German physicist Gustav Kirchoff (1824-1877) proposed a law of radiation that stated, "At a given temperature the ratio between the emissive and absorptive power for a given wavelength is the same for all bodies". Hence any object at some non-zero temperature will radiate electromagnetic energy. However, there was a problem: how could one match the known emitted radiation of a "hot" object to a theory? This phenomenon became an area of interest for many scientists in the latter half of the 19th century. Could a theory be found that accurately predicted the experimental spectral energy distribution data?

By the time Planck became interested in this problem, two basic laws had been established. Wien's law successfully represented the thermal



The complete model consists of the basic head (minus mouth, eyes, brow, and nose), and 20 attachable pieces comprising 9 mouths, 5 eyes, 4 brows, and 2 noses. These parts make possible 360 combinations. (A. J. O. P. Oct. 1923: 471-485; Oct. 1924: 602-604; Oct. 1926: 565-570)........ 73.50



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What are scientific instruments other than metaphors that lead us to look at various aspects of the world in a new light? Borrowing American philosopher Donald Davidson's explanation of how a metaphor works, one can argue that the scientific instrument helps us see one thing as another by making some literal statement that inspires insight. In this light, Boring and Titchener's facial keyboard may well be a metaphor of a metaphor, or a meta-metaphor. But what insight does a meta-metaphor yield other than indeterminacy and uncertainty? What is to be held true?

Such questions plague us only if we imagine our concepts to be more than the means we create to negotiate both the world and our intersubjective language community. We would do well to view our notion of reality as part of our ontological apparatus and to recall that our notions of concrete or abstract objects are of our own making, along with natural science and mathematics. Such intersubjective, conceptual creations allow us to systematize and revise our views of the world and are very much akin to the technological creations that transform the way we perceive and think about aspects of our world. If we understand the instruments we build and employ in science as metaphors, then we save ourselves the theoretical trouble that follows the compulsion to attach a supplementary certainty of meaning to such instruments.

An Interesting Matter --
A "Negative Fact" of Unclear Provenance:
Thoma Sledge Microtome vs. Spencer Microscope

C.S. Halloran

Which instrument makes a fact of anatomy? The microtome, which makes accessible that which is otherwise not, or the microscope, which magnifies that which is too small to be seen otherwise?

The fact surrounding these instruments involves a past Harvard professor, William Morton Wheeler (1865-1937), who challenged the prevailing theory of ant neurology formulated by the authoritative French invertebratologist Félix Dujardin (1802-1860). Dujardin and his supporters investigated a specific set of structures in the brains of the order Hymenoptera (ants, bees, wasps, etc.) known as the "pedunculate bodies," so named for appearing to have a peduncle (or stalk)

Dujardin believed that there was a correlation between the size of the pedunculate bodies and insect castes' intelligence. The problem-solving worker caste had the largest. Females came next, and the male caste, around mostly just to reproduce the species, had by far the smallest.

This whole inquiry was much bigger than just insects! Some anthropologists at the time were involved in a similar project to correlate sex and race superiority to systematic differences in brain size. If this was recapitulated elsewhere in the animal kingdom, these anthropologists' position would be strengthened.

Making the Fact

Wheeler's fact is that the pedunculate bodies do not invariably follow Dujardin's caste hierarchy. Wheeler, a specialist on ants (family Formicidæ), collected all castes of three unlike species. Then, Wheeler embedded his specimens, probably in paraffin wax, for stability during slicing; with the microtome sliced through their heads producing micrometers-thick sections (as thin or thinner than this line |); and finally prepared the slides for examination under a microscope. Only here did the fact come fully to light.

But then, what does Wheeler say of Dujardin's hypothesis that these structures are "the insectean analogue of the human fore-brain"? Wheeler actually could not say much. His fact was a "negative fact." It refuted the evidential support of a theory. It said nothing for or against the conclusion of that theory. Thus, Dujardin's theory was not wrong per se; it just was not correct as argued.

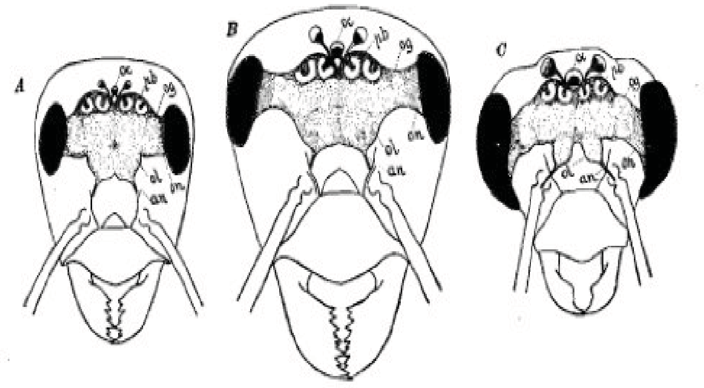


FIG. 29. Heads of worker (*A*), female (*B*), and male (*C*), *Formica fusca*, drawn under the same magnification, with brain, eyes and ocelli viewed as transparent objects. (Original.) Letters as in Fig. 28.

This is one of three figures Wheeler inserted into his tome *Ants: Their Structure, Development, and Behavior* (1910) to illustrate his fact (pg. 55). The pedunculate bodies are the four cashew-shaped structures overlayed onto the forehead of each ant's head. Note that the size of these structures does not go from largest to smallest from left to right according to Dujardin's theory.

Why this is so may reflect the purposes behind the instruments' designs. They were designed to make general observation possible, not to lend credence to any one theory or another. Of course, some assumptions are made when using both instruments. First, the microtomist assumes that a well-produced cut does not change the anatomy. Also, the microscopist assumes that the microscope only magnifies the image and does not change it. Nevertheless, even if these assumptions were to fail to hold up, their effects on the produced "facts" would be systematic. As a result, Wheeler's observations and conclusions would still hold so long as he prepared all specimens with this microtome and a microscope with the standard attributes of this one.

Thus, I leave the answer to my first question to you: Which instrument made the fact—the microtome, without which the internal anatomy of the ant could never be seen, or the microscope, which enables the actual act of seeing?

Facial Keyboard

Jason Miller

In 1923, Edward B. Titchener, student of Leipzig psychologist Wilhelm Wundt, and Edwin G. Boring, who established the first independent department of psychology at Harvard, wrote a short paper titled "A Model for the Demonstration of Facial Expression." In it, Titchener and Boring describe a wooden device that consists in "various brows, eyes, noses and mouths that can be fitted into place after the manner of a puzzle picture" to create 360 possible combinations, leaving only a few "senseless" combinations. By creating this device, which they hoped would transform the lecture-room into the laboratory, Titchener and Boring were trying to show that given meanings could be attached to given simple expressions. The paper closes with the authors' advice on how best to arrange the device in order "to prevent confusion and consequent loss of time," while one "manipulates his facial keyboard." The "facial keyboard" was mass-produced and used for decades in labs and lecture halls, and its digital descendents still populate research institutions today.

The term "facial keyboard" suggests a relation between expression, language and meaning. In Titchener's, "An Outline of Psychology" emotive expressions played a necessary role in the evolution of primitive human language. In attempting to persuade his reader of this claim, he addresses the topic of abstract words, and conjectures their derivations always "contain a metaphor, i.e., that they originally designated something concrete." For example, "black is 'that which is scorched'; an animal is 'that which breathes'; to explain is to 'spread out' or 'level.'" Titchener speculates, "complex states of mind, such as emotion, would be spoken of … in a metaphorical … way, and that the spoken word would be eked out by gesture." For, the "metaphor brings the … 'look' with it; and the 'look' persists as a constituent in the total emotive expression, because of its original utility for the communication of ideas." The notion of expression as an ancient remnant of useful habits comes from Darwin's work on the subject, but I am pointing to the importance that metaphor, taken from the familiar incidents of everyday life, played in Titchener's thinking on the verbal and facial expression of abstract and complex mental states.

Turning away from the Sun

The backstaff, also known as the Davis Quadrant after its developer John Davis, was used by sailors to determine latitude by reading the relative altitude of the sun or the pole star. By turning one's back to the sun and allowing it to cast a shadow on the calibrated settings, mariners were able to figure out the height of the sun at its highest point in the day. This information enabled sailors to figure out their latitude and thereby give a relative idea of position. The backstaff improved on its predecessor, the cross-staff, by allowing the readers to turn away from the sun which both increased the ease of measurement and the range since higher altitudes could be recorded.

This particular backstaff was most likely produced in Salem, Massachusetts in 1775 by Benjamin King. While the maker is not certain, this piece was made in Massachusetts in the latter part of the eighteenth century. The Massachusetts coast was the primary source of backstaffs for most of the colonies. This backstaff was actually made after the more accurate octant was developed in New York by Anthony Lamb, but backstaffs were cheaper and easier to use so they kept being used and produced.

Portable, Probable Locations

The backstaff enabled sailors to apply the precision of maps on land to moving ships. Maps with lines of longitude and latitude were only useful when latitude and longitude were known with some degree of precision. The backstaff allowed navigators to assign numerical interpretable values to any particular position. This process of 'papering' the natural world with measurements expanded the reach of the network of facts that were used in navigation. The backstaff helped in effectively expanding the existing network of locations shown by maps onto charts of oceans without visual cues to help with navigation.

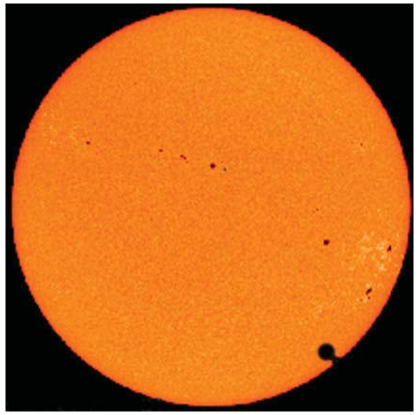
While the backstaff was very effective in finding latitude and giving a rough estimate of location, its effect was restricted by the lack of accuracy in determining longitude. Longitude could not be calculated with any definition on most ships until the middle of the nineteenth century. Therefore the definition of location had to be adjusted to deal with a limited knowledge of longitude. This took the form of changing sailing patterns to attempt to stay on the same line of longitude and crude estimates of longitude based on the speed of the ship. These less precise methods underscore the benefits of having the 'papered' facts of the backstaff while at the same time limiting their effectiveness.

The Astronomical Transit:
Observation, Standardization, and Scientific Fact

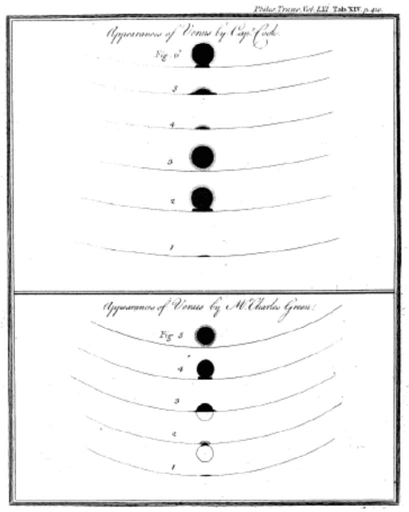
FeiFei Jiang

What allowance is there for human error in the calculation of scientific standards? In any empirical, scientific experiment, the results achieved are analyzed for experimental errors, whether they stem from imperfect conditions, faulty equipment, or human mistakes. Though experimental error is assumed, a certain margin for error is also assumed. However, when translating these experimental results into exact standards for science and society as a whole, their accuracy is assumed. What happens when accuracy is impossible? The astronomical transit, an example of which is shown here, was at the center of a nineteenth-century debate over human error, observation, and the determination of the standard length of the solar parallax (the distance from the Earth to the Sun, now standardized as the Astronomical Unit). Like the meter for geographical distances, the astronomical unit has now become a standard measure for astronomical distances, but its path to standardization was filled with controversy.

The transit of Venus—first in 1874, then again in 1882—was a rare astronomical phenomenon where Venus would pass between the Earth and the Sun. This event was regarded by astronomers of the time as a rare opportunity to use the measurements of Venus's transit across the sun to resolve ambiguities concerning the exact length of the solar parallax. The transit, however, sparked a crisis in astronomy at the time relating to human reaction time and recorded measurement. This crisis centered around the problem of the "personal equation," the personalized amount of error with which each individual observer recorded transit times. These discrepancies, both between different observers as well as between observed and actual times, posed great problems in terms of accuracy and consistency, issues that could not be allowed to cloud measurements whose precision and accuracy were crucial.



A mysterious black "drop" was one "artifact" that, in addition to the personal equation, caused problems for the observation of nineteenth-century transit. The mysterious "drop," which we now know was a visual phenomenon caused by the dark shadow of Venus crossing close to the extremely bright edge of the Sun, made it even more difficult for astronomers to determine the exact time of contact. The drawings above by James Cook were made of the 1769 transit of Venus, and show his observations of the black "drop." The 2004 photo, below, again shows the phenomenon of the "black drop," which even occurred in photographs of the time.



As historian of science Jimena Canales states, astronomers increasingly held the view that "only by measuring the personal equation could one 'come closer to the truth,'" and thereby determine completely accurately the dimensions of the solar system. Increasingly, then, the observer was relegated to the bottom of a progressively more complex and structured observatory hierarchy. The observer became like the astronomical transit, together seen as mere instruments to be calibrated.

The accuracy of the measurements for the transit was crucial at the time, not only to determine a standard based on "truth," but also to make the argument that the unit was based on "divine" distances. The historian of science Simon Schaffer has made a case study of the importance of the "divine" to the determination of standards of measurement in Victorian England. In fact, Schaffer describes Charles Piazzi Smyth, at the time a proponent of discovering "divine" standards of measure, as having "correctly, and delightedly reported that the transit expeditions had failed…Smyth pointedly contrasted human failure with divine certainty."

The well-known French theorist Bruno Latour's ideas about the making of science are especially applicable in this case. Looking at science as Latour does, as an abstraction of the outside world, makes the problem of the personal equation seem like a natural

occurrence, and one easy to resolve. Any values determined for the transit times of Venus, and the value of the solar parallax thereby calculated, are only one abstraction, a representation of the "real". Indeed, a Latourian might see any one of the various transit values as valid, as long as it had sufficient strength of argument backing it to support a sustainable network. The real value in precision, for Latour, would only be to facilitate a greater claim to legitimacy and a strengthening of the "network" of the solar parallax ideal.

We might say, then, that along with the astronomical transit, the "instrument" of the observer also lay at the center of issues surrounding transit observations in the nineteenth century. In the end, the search for the solution to the problems posed by the personal equation, more than anything, exemplified the idea of establishing scientific validity as a social and political phenomenon. Though the astronomical unit was eventually standardized not by astronomers, but rather by physicists measuring the speed of light, the problem of the "personal equation" remains an intriguing case study in the formation of scientific standards.

The Backstaff:
Determining Latitude and Grasping at Position

Kyle Magida

How do you figure out where you are on the planet? Answering this question on a moving boat in the middle of an ocean with no visible landmarks is essential for determining travel patterns and paths of exploration. Navigators from the sixteenth century through the end of the eighteenth century were able to determine one aspect of position, latitude, with relative accuracy. The longitudinal readings necessary for precise location were much more difficult to compute and therefore position was determined primarily through latitude.