Could Coulomb's Experiment Result in Coulomb's Law?

OLDENBURG, GERMANY—Imagine you are working late in the laboratory. You have been trying for days to get your experiment to give you the results you expect. Some of the data agree with your theory; many do not. But in your heart you know the theory is right; there must be some problem with the apparatus. Now if you just publish the values that agree with the theory and discard the others as "bad trials," that would solve the problem. When you are later proven right, who will know the difference?

If you find this temptation frighteningly familiar, take heart: You may have some illustrious company. One of the pioneers of modern physics, Charles Augustin Coulomb, may well have gotten away with manipulating his data in just this way while deriving the famous law now named after him.

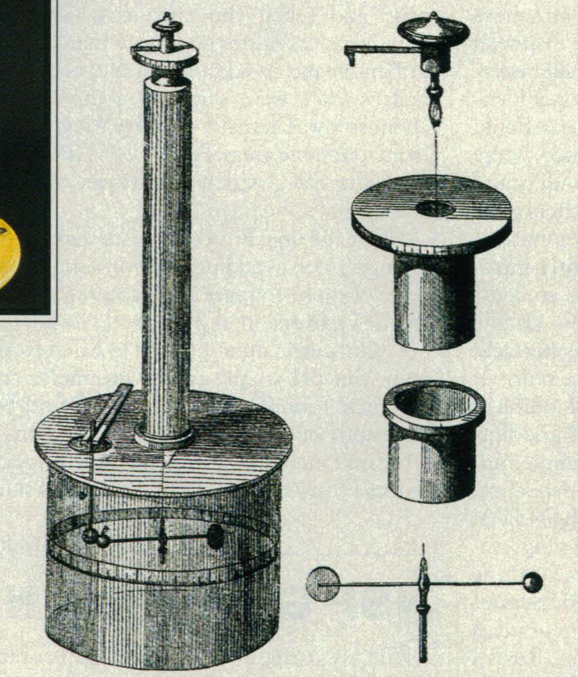
Falk Riess and Peter Heering, historians of science at the University of Oldenburg in Germany, arrived at this conclusion after painstakingly building a torsion balance modeled on the one Coulomb used in 1785 to demonstrate his law of electrostatic forces between charged objects.

Riess and Heering are well known in the history of science community for constructing replicas of scientific equipment and using them both for scholarship and science teaching. The pair have reconstructed apparatus used in more than 20 physics experiments from the 16th to the 19th centuries. They obtained the results reported by the original researchers in every case except one. The German historians found that their apparatus failed to confirm Coulomb's law reliably, and the implication, they believe, is that Coulomb was economical with the truth.* That interpretation is not universally shared by other historians of science, however. And even Riess and Heering agree that, while Coulomb's scientific method may not have been up to today's standards, he was an inspired scientist and should receive full credit for his discovery.

Coulomb was one of the world's experts on torsion, and he put this expertise to use in trying to find a law governing electrostatic force. His apparatus consisted of a stationary metal ball and an identical ball on one end of a counterbalanced horizontal beam that was suspended on a fine metal wire so that it could swing freely. The whole set-up was enclosed inside a glass cylinder.

Coulomb put a static electric charge on the stationary ball and then twisted the wire so that the ball on the beam swung round and touched it. The charge was instantly shared

FALK RIESS



Delicate balance. Coulomb's 1785 drawing of his apparatus *(below)* and Riess and Heering's reconstruction of the experiment *(left)*.

between the two balls, which then repelled each other. By twisting the wire back a certain amount against the force of repulsion, Coulomb could measure this force as a function of the distance between the balls. His published results show that the balls repel each other with a force inversely proportional to the square of their distances—Coulomb's law.

After reconstructing the apparatus, Heering took the role of experimenter and attempted to repeat the experiment as Coulomb described it. But try as he might, Heering could not get the results that Coulomb claims to have found. "I came up with all kinds of laws," he says. "Most of them were not simple." A few results agreed with the theory, but only a small proportion. Heering concludes that Coulomb must have derived his relation mainly from theoretical considerations: Scientists at the time expected an inverse square law for electrostatic forces similar to Newton's law of gravitational attraction. Since that is what Coulomb was looking for, says Heering, that is what he found. Heering and Riess admit, however, that the key piece of evidence—the complete set of his original data—is missing.

But the researchers say they have another critical clue. In his 1785 treatise on electricity and magnetism, Coulomb said that the charged ball on the beam oscillated back and forth a few degrees in either direction, "regardless of how still the air is." Coulomb made no analysis of what caused the oscillations but compensated for this potential inaccuracy by giving the wire a 30 or 40 degree twist at the beginning. According to Coulomb's treatise, the additional torsion in the wire damps the oscillations enough to eliminate this uncertainty.

Heering observed similar oscillations but, in contrast to what Coulomb reports, twisting the wire alone was not sufficient to ensure results that confirm the inverse square law. Heering believes the oscillations were caused not by stray air currents but by a static electric charge on the experimenter. No matter what he did, Heering says, he was unable to obtain the expected results while he was charged: He inevitably transmitted the charge to the apparatus, leading to a wide variety of results. The only way he could eliminate the effects of this charge was to isolate electrically the entire apparatus from its surroundings by enclosing it in a conducting box or "Faraday cage," a technique not known until decades after Coulomb's experiments. Then and only then did Heering obtain the expected results.

It might seem surprising to a modern scientist that none of Coulomb's contemporaries in France questioned his results, especially since Coulomb's treatise contained only three pieces of data to support his hypothesis. But it was common practice at the French Academy of the time to provide only a few data points as proof, and statistical analysis was introduced only in the 1840s. Riess adds that Coulomb's results fit in perfectly with what the French scientific community expected, so few people were inclined to try to disprove them. Moreover, even if someone had wanted to try to repeat

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his experiments, few had the necessary expertise in making torsion balances.

Not every historian believes that Heering has proven Coulomb to have been guilty of data manipulation. Maria Trumpler, a Yale historian of science who has worked extensively on the history of electrical experimentation, says there is a fundamental problem with any historical reconstruction: "The only test to see if you have in fact reconstructed what [the original researchers] have done is if you get the data they get." There is no way to know if Heering was really true to the conditions under which Coulomb carried out his experiment, she says. "Did he dress in the same clothes? Did he wear the same kind of powdered wig?" Riess says he and Heering took these factors into account, even though he admits that it was not possible to reproduce the original conditions exactly. "We have thought of what Coulomb could have done to avoid a charge on his body," says Riess. "He could have been perfectly grounded but that would have been very complicated. Or he could have been naked. But he didn't report taking any of these precautions."

MIT historian of science Jed Buchwald also has doubts. There are other methods that Coulomb might have used to counteract the effects of a charged observer, he says, without mentioning them in the treatise. For example, Coulomb may have moved away from the apparatus after imparting the initial charge and read the angle of deflection using a telescope, a well known technique at the time.

Buchwald, a highly respected historian who is familiar with Riess' and Heering's work, says he regards them as reliable researchers. "If they say they saw this effect [of the oscillations], then they saw it." Buchwald is certain of his final decision, however: "I do not believe for one second that Coulomb had 20 pages of numbers and that he kept calculating through until he found three that worked." Coulomb was too good a scientist for that, he says.

Riess and Heering agree that Coulomb was a great scientist. They are quick to point out that at the time, other electricity researchers would measure the strength of an electric charge by giving themselves a shock with it and seeing how far they could feel it go up their arms. In comparison, Coulomb's work is refreshingly quantitative. At least in principle, it was possible to use the torsion balance to make reproducible measurements.

Trumpler adds that even if Riess' and Heering's claim is correct, Coulomb should be applauded for coming up with the right result: "If we assume that in this case the data were not sufficient to determine the theory, then we have to acknowledge that Coulomb had tremendous insight." Furthermore, says Trumpler, the eagerness of many modern scientists to obtain "zillions" of reliable data points may have lessened the emphasis on scientific intuition. "The ability to have a profound insight about the nature of how things work based on just a few data points," says Trumpler, "is becoming a lost art."

–Steven Dickman

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ENVIRONMENT

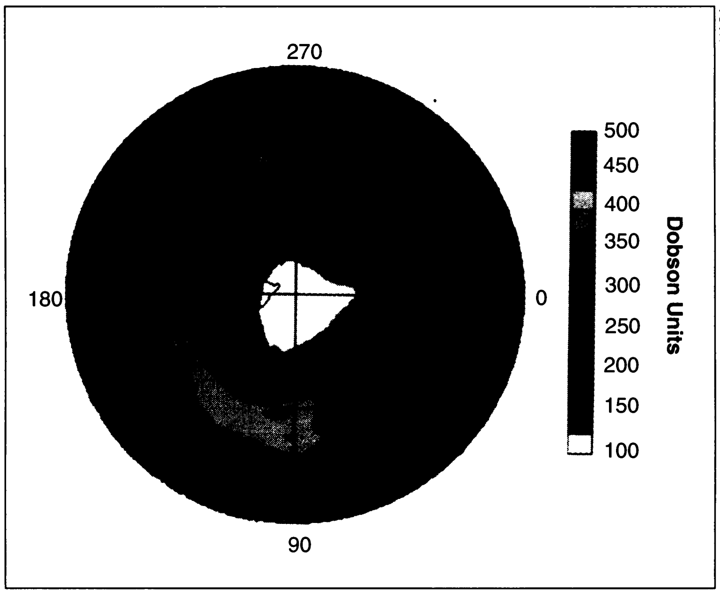
The Ozone Hole Reaches a New Low

Most scientists thought the ozone hole couldn't get much deeper. But the annual thinning of the ozone layer over Antarctica has broken another record. Balloon and satellite measurements during this year's Southern Hemisphere spring reveal 15% less ozone over Antarctica than during last year's thinning, leaving the protective ozone shield at less than one-third its normal thickness.

Announced last week, the additional losses are a surprise because in recent years the depletion of ozone has been almost complete at the altitudes where conditions normally favor its destruction by chlorine from manmade chlorofluorocarbons (CFCs). Only if favorable conditions, including extreme cold and the presence of the fine particles that trigger the ozone depleting reactions, had spread to other altitudes could more ozone disappear. And that's just what scientists think may have happened, thanks to lingering debris from the 1991 eruption of Mount Pinatubo and perhaps unusual cold at high altitudes.

The erosion of Antarctic ozone appeared on schedule, says David Hofmann of the National Oceanic and Atmospheric Administration in Boulder, but by early October it had extended well beyond the region where ozone loss had tended to be complete: a 1- to 2-kilometer-thick layer centered at an altitude of 17 kilometers. Instead, balloon-borne instruments showed total depletion from 14 to 19 kilometers. All told, just 90 Dobson units (DU) of ozone were left in the Antarctic stratosphere this spring, compared to 105 DU last year, which in turn was 5 to 10 DU below preceding years. (At other seasons, Antarctic ozone levels are about 280 to 300 DU.)

Something similar, but not as dramatic, happened last year, when heavy ozone depletion was seen for the first time at altitudes below 14 kilometers, says Hofmann. Since the high-altitude ice clouds that activate ozone-destroying chlorine are centered at an altitude of around 17 kilometers, researchers concluded that something else had to be taking their place at lower altitudes. The best candidate seemed to be the haze of sulfuric acid particles lofted by Pinatubo's eruption. And that same, lingering haze is probably to blame for this year's low-altitude losses, Hofmann says.



NASA

Empty sky. On 6 October the TOMS instrument aboard the Russian meteorological satellite Meteor-3 found unprecedented ozone losses *(white)* within the ozone hole *(blue, magenta, and white)*.

Volcanic haze doesn't explain the enhanced losses seen between 18 and 23 kilometers, however; there is no significant Pinatubo debris above 18 kilometers over Antarctica. Hofmann wants to look at more data, but he suspects that colder-than-normal temperatures at high altitudes might have encouraged the formation of more ice cloud particles, laying the groundwork for more ozone loss.

For the time being, researchers are assuming that this year's record losses don't mean that they have to rethink their understanding of Antarctic ozone depletion. Next year's hole should tell: Providing stratospheric temperatures are normal and most of the Pinatubo debris has settled out, the hole should be back to "normal."

–Richard A. Kerr