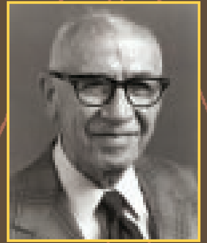
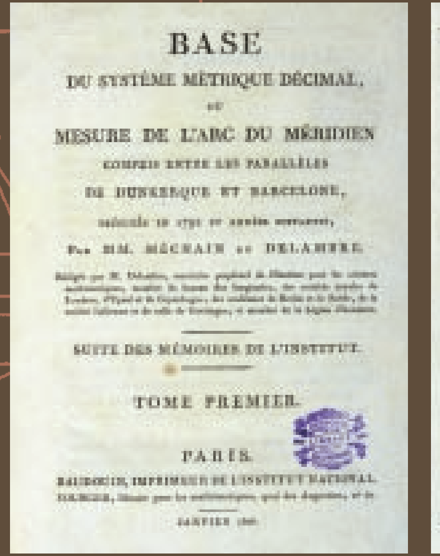
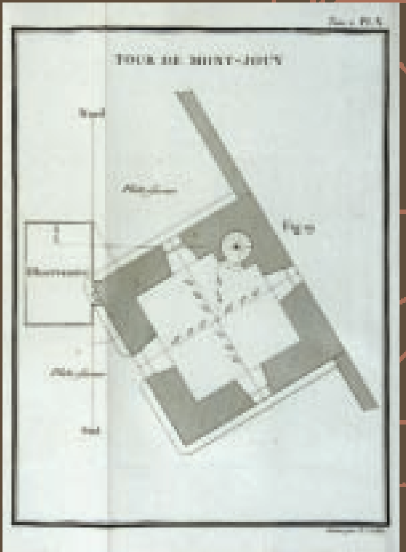


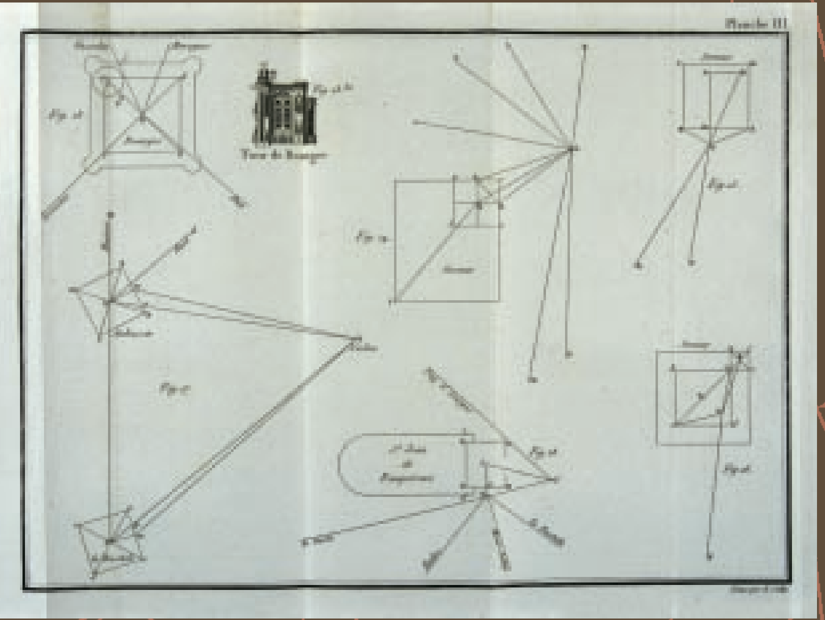
THE APPROXIMATELY 10,000 VOLUMES of rare books and the 1,600 manuscript groups in science and technology originally donated by the Burndy Library to the Smithsonian Institution Libraries form the core of the Dibner Library's collection. Over the years, the collection has been supplemented by the Smithsonian's own holdings and gifts from individuals and institutions, and now numbers some 25,000 rare books and 2,000 manuscript groups. The Dibner Library's holdings are contained within and searchable via the Smithsonian Institution Libraries' online catalog, SIRIS.

Heralds of Science

The most widely recognized portion of the Dibner Library are the "Heralds of Science," 200 works selected by Bern Dibner as the most significant titles in the formation and development of Western science and technology. They were presented in his classic book, *Heralds of Science* (Norwalk, Conn.: Burndy Library, 1955; reprinted in 1969 by Cambridge, Mass.: MIT Press; revised edition in 1980 by Burndy Library and Washington, DC: Smithsonian Institution). Dibner came up with eleven general categories and briefly described his choices of the greatest works that represented those disciplines. The works described in *Heralds of Science* continue to stand as major milestones in the history of science and technology. The publication is often cited in rare book catalogs (a particular volume is always referred to by its Heralds number) and is a tribute to the vision of Bern Dibner.


BASE
DU SYSTÈME MÉTRIQUE DÉCIMAL,
OU
MESURE DE L'ARC DU MÉRIDIEN
COMPRIS ENTRE LES PARALLÈLES
DE DUNKERQUE ET BARCELONE,
Par MM. MÉCHAIN et DELAMBRE.
SUITE DES MÉMOIRES DE L'INSTITUT.
TOME PREMIER.
PARIS.





Smithsonian Institution Libraries

KEN ALDER

THE MEASURE *of* THE WORLD

DIBNER LIBRARY LECTURE

5 NOVEMBER, 2003

SMITHSONIAN INSTITUTION LIBRARIES

RAISED IN BERKELEY, CALIFORNIA, Ken Alder was part of a bussing program to achieve racial integration, an experience which served as the subject of his first novel, *The White Bus*, published by St. Martin's Press in 1987. Alder studied physics at Harvard University, where he also received a Ph.D. in the history of science in 1991. His first book of history, *Engineering the Revolution*, examined the relationship between the French Revolution, science, and military technology. It was published by Princeton University Press in 1997, and won the 1998 Dexter Prize for the best book published in the field of the history of technology.

Since 1991, he has taught at Northwestern University, where he is Professor of History and directs the Science in Human Culture Program. He is also the Milton H. Wilson Professor in the Humanities, and has held research grants from the National Science Foundation, the National Endowment for the Humanities, and the American Bar Foundation. His most recent book of history, *The Measure of All Things: The Seven-Year Odyssey and Hidden Error that Transformed the World*, was published by The Free Press (New York) and Little, Brown (London) in 2002. It has won the Davis Prize of the History of Science Society, the Dingle Prize of the British Society for the History of Science, and the Kagan Prize of The Historical Society. *The Measure of All Things* is being translated in fourteen languages, and is also the source of his 2003 lecture at the Dibner Library, from which this book was derived.

Alder's current project examines the history of the forensic sciences in France and America from the seventeenth century to the present. The first installment of this project will be a book on the history of the American lie detector in the twentieth century. Alder lives with his wife and daughter in Evanston, Illinois.

COVER DESIGN BY MARC ALAIN MEADOWS
AUTHOR PHOTO BY JERRY BAUER

THE MEASURE *of* THE WORLD

IN COMMEMORATION OF THE
THIRTEENTH ANNUAL
DIBNER LIBRARY LECTURE SERIES

THE MEASURE *of* THE WORLD

by KEN ALDER

DIBNER LIBRARY LECTURE

5 NOVEMBER · 2003

SMITHSONIAN INSTITUTION LIBRARIES
WASHINGTON · DISTRICT OF COLUMBIA

Published by
Smithsonian Institution Libraries
Washington, DC 20013-7012

Text © 2003 Ken Adler. All rights reserved.

Ken Alder is Professor of History and holds the Milton H. Wilson Professorship in the Humanities at Northwestern University. His most recent book, *The Measure of All Things: The Seven-Year Odyssey and Hidden Error that Transformed the World* (New York: The Free Press, 2002) won the Davis Prize from the History of Science Society, the Dingle Prize of the British Society for the History of Science, and the Kagan Prize of The Historical Society. It is being translated into fourteen languages. More complete references to works cited in this paper can be found in the published book from which this talk is drawn.

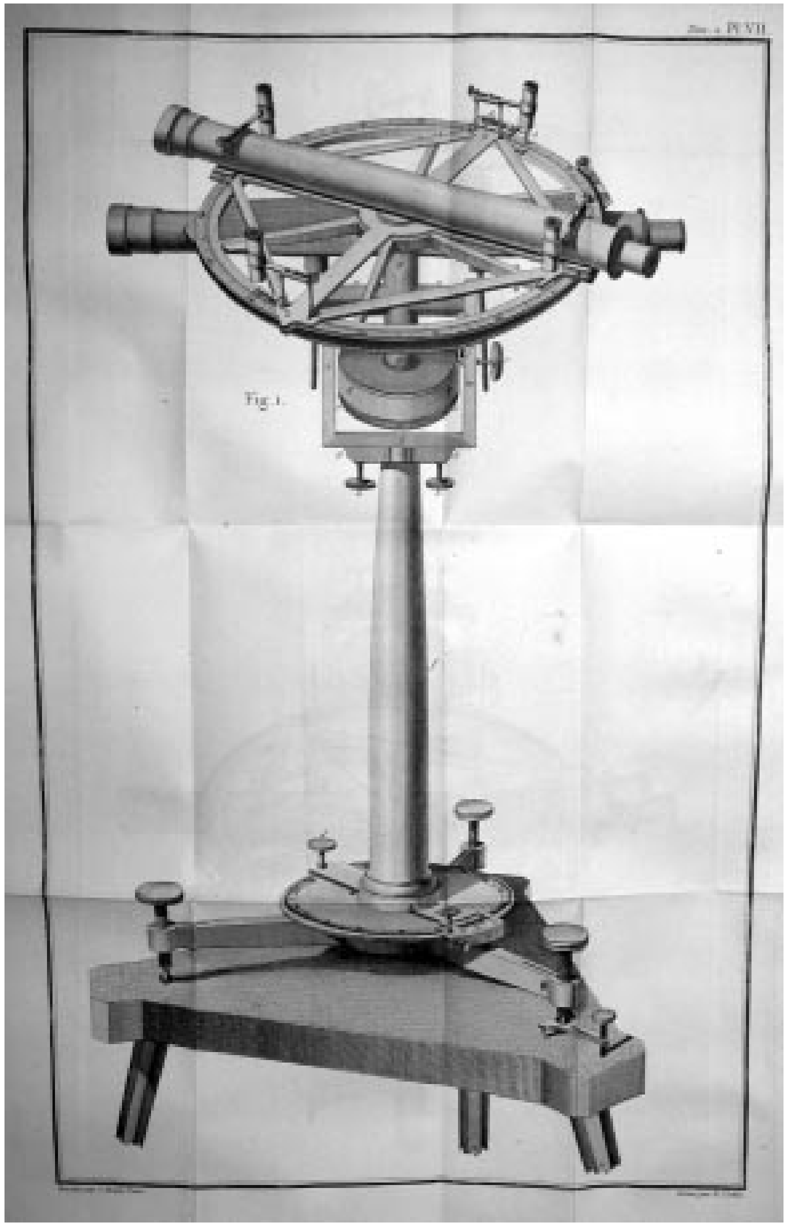
Edited by
Robert Kearns

Designed and typeset by
Marc Alain Meadows
Meadows Design Office, Inc., Washington, DC, www.mdomedia.com

Library of Congress Cataloging-in-Publication Data
Alder, Ken.
The measure of the world / by Ken Alder.
p. cm. — (Dibner Library lecture)
Includes bibliographical references.
1. Mensuration—History. 2. Weights and measures—History. 3. Metric system—France—History. I. Title. II. Series.

QA465.A264 2004
530.8´12—dc22 2004015833

back cover, clockwise from top left: *Cover from volume one of J.-B.-J. Delambre's* Base du système métrique décimale *(Paris, 1806–10); Plan of the Tour de Mont-Jouy from volume 2, plate X; Triangulations for the Tour de Bourges, plate III.*



THE BORDA REPEATING CIRCLE

Foreword

Measures matter." This underlying theme in Professor Ken Alder's prize-winning book *The Measure of All Things: The Seven-Year Odyssey and Hidden Error that Transformed the World* (2002) also informs his essay presented here as "The Measure of the World." Professor Alder has chosen something we all take for granted, the meter, and, in a tale that combines scientific curiosity, derring-do, and incipient madness, shows how its length was established in the eighteenth century. I look at it as the quintessential reason why we should take nothing for granted, and also why the Smithsonian Libraries' strong collections in the history of science and technology, wherein these kinds of stories lie, also matter.

The Smithsonian Libraries is proud to present Professor Alder's essay as the thirteenth annual Dibner Library Lecture, a series begun in 1991 on varied topics and themes, all sharing a common element of using the rich resources of the Libraries' Dibner Library of the History of Science and Technology. In this case, Professor Alder, the Milton H. Wilson Professor in the Humanities at Northwestern University, points to the value of a manuscript letter in the Dibner Library's collection that helped him to recreate the voyage of the French astronomer Jean-Baptiste-Joseph Delambre, who, with his partner François-André Méchain, was responsible for performing the work that led to establishing the length of the meter. Delambre's letter might not have been available to Professor Alder, had it not been acquired by Bern Dibner (1897–1988), the individual responsible for bringing together the remarkable collection of books now housed in the library that bears his name.

Bern Dibner was an electrical engineer, book collector and philanthropist who donated 10,000 rare scientific and technological books and manuscripts from his Burndy Library to the Smithsonian Institution on the occasion of the United States Bicentennial celebration in 1976. The Dibner Library of the History of Science and Technology, the Smithsonian's first environmentally controlled and staffed rare book facility, formed the basis of an active special collections program that has resulted in holdings of more than 40,000 rare books and manuscripts. The Library contains many major scientific works dating from the fifteenth to the early nineteenth centuries in engineering, transportation, chemistry, mathematics, physics, electricity, and astronomy. The Dibner Fund supports a variety of programs designed to share the riches and value of the Library with the general public and to bring students and scholars to use its collections.

We thank The Dibner Fund for its generous support of the Dibner Library Lecture series and its publications.

For more information, please visit the home page of the Dibner Library of the History of Science and Technology at: www.sil.si.edu/libraries/dibner. To read Dr. Alder's lecture and see a list of all the other Dibner Library Lectures, go to: www.sil.si.edu/exhibitions/lectures.htm.

NANCY E. GWINN, DIRECTOR
SMITHSONIAN INSTITUTION LIBRARIES
APRIL 2004

PIERRE-FRANÇOIS-ANDRÉ MÉCHAIN

JEAN-BAPTISTE-JOSEPH DELAMBRE

The Measure of the World

Many of you, I'm sure, remember a news story from four years ago: the story of the NASA satellite known as the Mars Climate Orbiter, launched from Florida in 1999 to map the Martian terrain. And I'm sure you remember it for an unfortunate mishap. Just as the Orbiter was to settle into its final approach to the Red Planet, making a final swing around the far side of the planet, it went missing, having presumably crashed into the planet's surface. What had gone wrong? An investigation revealed that one set of NASA engineers had been using units based on the metric system and another was using the traditional Anglo-American units. The result had been a sixty-mile trajectory error and the loss of a $125 million investment.

From this embarrassing fiasco, I would like to extract a simple lesson: measures matter. If fields of human endeavor were to have official mottoes the way that nations do: the motto for science might well be "In measures we trust." As the great 19th-century physicist, Lord Kelvin, put it:

> *If you can measure that of which you speak, and can express it by a number, you know something of your subject; but if you cannot measure it, your knowledge is unsatisfactory.*

This I take to be British understatement for "you don't know what you are talking about."

But measurement is more than the language of science, it is the language of commerce, industry, and daily life. Measures are the language we use when we want to know how many, how often, how fast; whenever we want to buy or sell with exactitude. Measures are the standards against which we strike agreements and quantify our differences. Measures are the numbers we trust. Yet like most of those things we trust, we take measurement for granted. Indeed, measurement is so ubiquitous as to be invisible. Measurement is so ordinary, so "settled" that many people understandably consider it banal.

As a historian of science I study those truths and truisms which define an age. Measures may be a truism to us, but they have a surprising history. In the not-so-distant past, measurement had a radically different meaning than it has today. Because if the history of science teaches us anything, it is that truths and truisms change with the times. I wrote my recent book, *The Measure of All Things*,[1] to show readers how even those things we think of as self-evident and banal are born out of controversy and conflict, and that science—even the most exacting science—is the product of passionate effort by human beings beset with all the usual human frailties, as well as an equal allotment of courage.

I was in fifth grade in the mid 1970s when America made its last serious effort to join the metric system. At the time we were told by our teacher that we must all learn the metric system because it was inevitable, it was the language of the future. Already 95% of the world's people lived in countries that used the metric system—and America, she told us, would soon join them. Well, in the US, we are still waiting for that future to arrive. Of course, there is a paradox at work here because this puts America, the supposed leader of the movement for globalization, in the company of the only three countries in the world that do not

use the metric system, the other two being Liberia and Burma (Myanmar). As time went by and the metric system failed to arrive in America, I became curious about where this "inevitable" future had come from. What was the past of this future? I set out to ask a simple question: why is a meter a meter? Why is it a little more than a yard long?

My book, *The Measure of All Things* is the story of an extraordinary scientific expedition at an extraordinary time. In 1792, in the midst of the French Revolution, two astronomers were sent out in opposite directions on a mission to measure the size of the world. One astronomer, Jean-Baptiste-Joseph Delambre, was sent north from Paris and the other astronomer, Pierre-François-André Méchain, was sent south. Their mission was to measure the length of the meridian arc that runs from Dunkirk to Barcelona so that they might calculate the distance from the North Pole to the equator. By calculating that distance with unsurpassed precision, they would be able to set the length of a new measure—the meter—as one ten-millionth of the distance from the North Pole to the equator. Their goal was to establish this new global measure as the permanent standard for all the world's people. In the words of Condorcet, the great optimist of the Enlightenment, the meter was to be "for all people, for all time."

But why one ten-millionth of the distance from the north pole to the equator? Frankly, because the scientists knew the resulting unit would come out to something on the human scale—a little more than a yard long, otherwise known in Old Regime France as the *aune*, a very widely known unit for measuring cloth. But why measure the world at all? As one critic of the metric expedition wondered: "Was it really necessary to go so far to find what lay so near?"[2]

Measures in the eighteenth century did not just differ from country to country, but within each country as well. As one Englishman visiting France remarked, "In France the infinitive perplexity of measure exceeds all comprehension."[3] Measures might even differ from one parish to the next. For instance the pint in the town of Saint-Denis, just ten miles north of Paris, was roughly 25 per cent larger than the pint of Paris. France alone had some 250,000 different units of measurement in regular use. This mind-boggling diversity made travel a torture, impeded commerce, and invited easy fraud.[4]

The Revolutionaries in the new National Assembly—like the monarchists before them—wanted to rationalize this system so as to ease the administration of the state and rationalize (and intensify) taxation. But for the Revolutionaries, uniformity was more than an administrative convenience, it was integral to their political mission. After all, the diversity of old measures made it difficult for people to know how much they were buying or selling, and this, the Revolutionaries believed, made them dependent on others, and hence unfree. This problem was particularly acute in an age when few people were numerate. The goal of the metric system, then, was to make measurement easy and clear in the name of human equality and liberty. Why should people be subject to different rules depending on where they were born or of what social status? Were not all human beings entitled to the same rights and laws? So too should they all have the same weights and measures. But *which* weights and *which* measures?

The Revolutionaries were seeking to liberate France, but they also had universal aspirations. They wanted to repudiate the corrupt institutions of the Old Regime and mark a clean break with the past. This was to be history's great utopian rupture. The moment seemed to offer a chance to design the world anew. So rather than turn to any traditional national or regional unit as their new standard (such as the old Parisian measures), the Revolutionaries turned instead to nature, to something that lay outside any human institution and belonged to no single people. And because they wanted the new measure to be used by all people of the world, they decided to base their measure on the size of the world itself.

Of course Delambre and Méchain were not asked to measure the entire arc of the world. It was enough for them to measure a sector, sufficiently close to the 45th parallel so it could be extrapolated to the whole. As luck would have it, the only such meridian was the meridian that ran through France.

It was a mission of awesome responsibility: to create the definitive measure for all future scientific and commercial activity. The two men selected were known for their scrupulousness and integrity, as well as for their scientific ability. As Antoine Lavoisier, the father of modern chemistry, and one of the planners of the expedition, wrote to Méchain (the south-going astronomer): "You must not forget that you are carrying out the most important mission that any man has ever been charged with, that you are working for all nations of the world, and that you are the representative of the Academy of Sciences and all the savants of the universe."[5]

Talk about shifting the burden of Atlas onto someone else's shoulders! The years of the Revolution were not an easy time to travel through the French countryside making measurements of exquisite precision. How do you measure the earth, while the world is turning under your feet? For seven years the two men surveyed the terrain, travelling first in opposite directions, and then slowly measuring their way back toward one another. They had to climb cathedral towers, fortification turrets, steep hills, broken volcanoes, and their own self-built observation towers. It was the Lewis and Clark expedition of France, though admittedly along a meridian which had been measured fifty years earlier by the great Cassini. Indeed, the astronomers hoped to follow in his footsteps in order to speed up their mission.

But if the terrain was not "unknown," it was full of obstacles, the greatest of which were human. On many occasions the astronomers climbed a church tower to conduct their observations — peering with their instruments off into the distance—only to be denounced as spies or thrown into prison as counterrevolutionaries. They crossed battle fronts, survived life- threatening injury, stared down death threats from Revolutionary councils, and did constant battle with mistrustful peasants. At last in 1799 they met up in the southern fortress town of Carcassonne and returned together to Paris to present their data to an international committee of the world's leading scientists—the world's first international scientific conference.

Assembled there were the most illustrious scientists of Europe—Laplace, Legendre, Lagrange, as well as invitees from Holland, Italy, Spain (all those countries under French military authority). Together these eminent men calculated the length of the new measure—the meter—which they then enshrined in a bar of pure platinum, the world's newest and most precious metal. It was this bar that became the world's universal standard of measurement.

The great achievement was then written up in a monumental work, a three-volume, 2000-page account of the meridian expedition entitled: *Base du système métrique décimale*, which we might translate as *Foundations of the Metric System*.[6] The primary author of this work was Delambre, the north-going

astronomer, and in it, he proclaimed, were all the official data, formulae, and calculations that went into the making of the meter. Accepting this monumental three-volume book Napoleon declared: "Conquests will come and go, but this work will endure."[7]

As indeed it has—even as Napoleon's triumphs have come and gone. Today, the metric system is the official measurement for over 95% of the world's people. It is the universal language of measurement and a resounding success, an emblem of the benign effects of globalization.

Yet the *Base* is a strange book, and reading it, I began to wonder about some puzzling contradictions. At one point Delambre wrote that he had placed the original records of the meridian expedition—all his own logbooks as well as those of his colleague Méchain—on deposit in the Archives of the Observatory in Paris (a beautiful seventeenth-century building in the heart of Paris, just south of the Luxembourg Gardens). That way, anyone who did not trust his story could verify his account. I decided to do just that. I wanted to see for myself these amazing calculations—the methods by which seven years of scientific labor, tens of thousands of observations, had been boiled down into a single number: the meter. Measures after all, are the numbers we trust. What I found there was startling—even scandalous.

Delambre's logbooks are classics of their type. They are bound volumes, with numbered pages, written in ink, dated, and even signed at the bottom of each page.

Méchain's "logbooks" look nothing like this. They consisted of loose pieces of paper, written in pencil, unsigned, sometimes undated, and then pasted by Delambre into a large logbook and annotated in pen, and often retraced in ink. And at the end of

Méchain's logbooks, I found a lengthy handwritten note by Delambre, a note which closed with this comment:

Because I have not told the public what it does not need to know, I have suppressed all those details which might diminish its confidence in such an important mission, one which we will not have a chance to verify. I have carefully silenced anything which might alter in the least the good reputation which Monsieur Méchain rightly enjoyed for the care he put into all his observations and calculations.[8]

What "details" had been suppressed? Why had it been necessary to silence anything that cast doubt on the observations of Méchain? Part of the answer, I learned, lay in another set of documents in the same archives: a set of intimate letters between Delambre and Méchain; letters Méchain had often begged his colleague to burn; letters Delambre had placed under seal, so that they might not be opened; letters that had laid unread for two hundred years; letters that hinted at a terrible secret.

I had gone into those archives to learn about the meter, to try to understand how we have come to trust measures. What I learned was that the meter was wrong. It is short by about 0.2mm per meter, which is about the thickness of two pages of a book. And more scandalous still: I learned that the two men who had created the meter knew that their measurements were in error, and then kept that knowledge secret. But what does it mean to say that the meter is "wrong"?

To outward appearance—to the eyes of the sociologist, for instance—the two astronomers were remarkably similar men. Both were astronomers in their mid-forties from the provinces just north of Paris where they had been born to the lower "artisanal" order of society and trained by the same master astro-

nomer. But they were men of very different character, and that difference would decide their fates.

Delambre was the son of a rag-seller from Amiens, north of Paris. As an infant he had been stricken with small pox, which had infected his eyes. He permanently lost his eyelashes and was practically blind for most of his childhood. He did not take up astronomy until he was in his mid-30s, a time when most scientists are at the peak of their powers. This late start seems to have made Delambre a more worldly person, an erudite yet cosmopolitan bachelor. In short order he had risen to be one of the leading observational astronomers in France.

The method of these two men involved sighting large imaginary triangles and measuring their angles with a newfangled device: the Borda repeating circle. They also needed to measure a "baseline" along one side of one of the triangles so that they might calculate the dimensions of all the other triangles in the chain. And finally they needed to measure the latitude of the northern- and southernmost point of their meridian arc so that they might extrapolate from that distance to the entirety of quarter-globe.

Delambre performed his measurements with skill and exactitude. But his real talent lay in solving problems of a political nature. In the Auvergne, for instance, he had trouble sighting distances because the churches there are all black and hence difficult to make out against the background. In that volcanic region, all the church towers were composed of the black lava stone. So what did Delambre do? He wrapped a church tower in a white cloth (a kind of Cristo *avant la lettre*). The problem with this was that white was the royalist color and this angered the local peasants—not so much because they were anti-royalist, but because they did not want the big town twenty kilometers down the road to think they were royalists and attack them. So Delambre worked out a compromise; he attached a strip of blue cloth to one end of the sheet and a red strip to the other and called it a republican flag, making everyone happy.

One archival document in the Dibner collection was of great value to me in my efforts to re-create Delambre's voyage. It is a letter written by Delambre to General Calon, who was then the director of the *Dépôt de Guerre* in the years III-V. The *Dépôt de Guerre* was the body responsible for military cartography during the Revolution, and it had become the main sponsor of the meridian expedition when the executive branch lost interest in the expedition in the years of chaos after the Terror. The letter is dated *27 frimaire V* (17 December 1796), a time of intense hyperinflation in France, and it is mostly a plea for funding. It is written from the town of Evaux, which was the half-way point of the meridian expedition. In the letter Delambre writes that he only has 81 francs on hand and he will not be able to borrow money from a friend as he did the last time he ran out of cash. He says that most of the local inhabitants can't even sign their name, let alone read or write. They didn't speak French either, but a language known as Franco-Provençal. Even local officials have to ask him to read his authorization papers out loud to them. (Yet these were the people he expected would embrace the metric system!) He also notes that his results for the latitude of Evaux do not exactly match those found fifty years earlier on that same spot by Cassini, but that he, Delambre, has looked into Cassini's results and found an error in the way he calculated the refraction of light. And he closes his letter with a plea that Calon not deal too harshly with his distant partner, Méchain, who is stuck in the mountains to the south of him and who has accomplished so little these last few years. He writes:

I genuinely feel for Méchain who has run into such obstacles that his courage and determination have not been able to overcome them. I only hope that he will make it to Rodez this season [their intended rendezvous point] *and will be able to return to Paris for the season.*[9]

In fact, Méchain did not return to Paris that winter. Indeed, he did not measure any triangles during the next two years. At the time, Méchain was a man on the edge of madness, on the brink of suicide. He felt he had failed in his mission, which, according to Lavoisier, was "the most important . . . any man has ever been charged with." What had gone wrong?

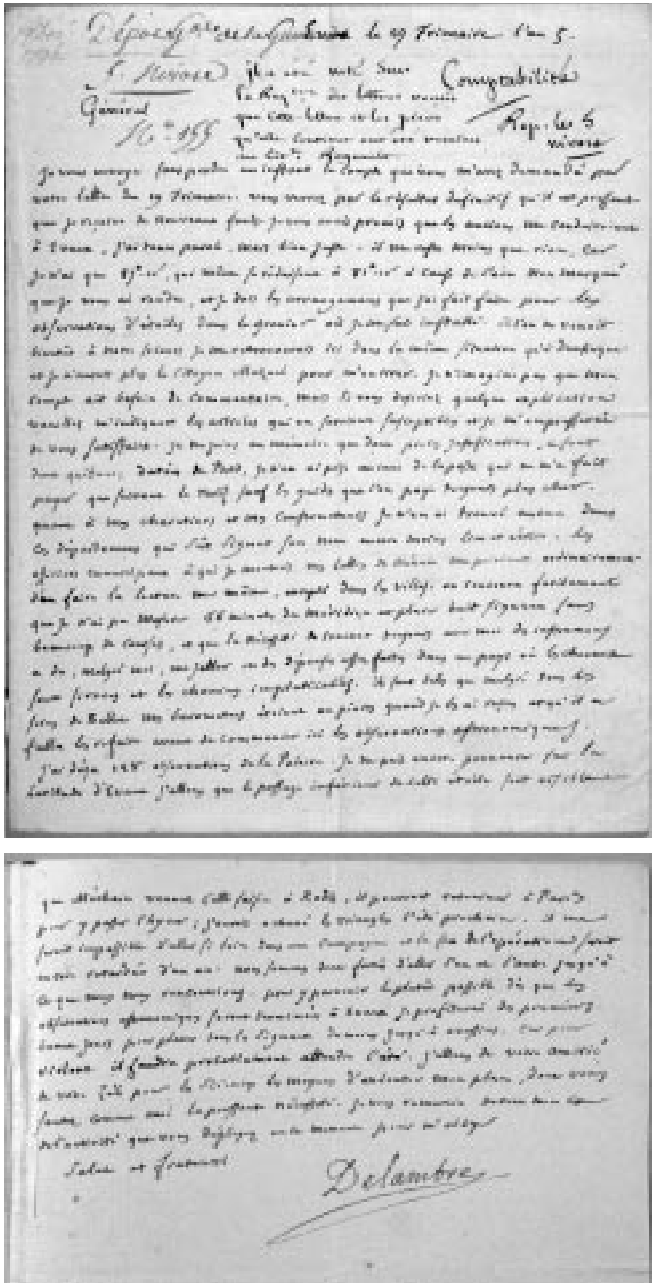
Méchain was the son of a small town plasterer who had labored for years in the bureaus of naval cartography, mapping seas he had never seen. At nights he scanned the heavens for comets and other celestial novelties from his home on the grounds of the Observatory. A cautious and fastidious man—a family man with three young children—his scrupulousness was born of self-doubt.

All had gone well for Méchain in the early phases of his mission. After quickly measuring almost all the triangles on the Spanish side of the border, in the company of Spanish military officers, Méchain had set up a make-shift observatory in the Mont-Jouy fortress just outside the town of Barcelona, the southernmost point of his portion of the arc. There, in the winter of 1792, he conducted astronomical readings that would pinpoint the latitude of the city, taking a total of 10,000 observations which he sent to Paris along with his calculation of the latitude.

At this point he considered himself done with the Spanish portion of his mission and was contemplating a return to France when two disasters struck in quick succession. First, war broke out between Revolutionary France and royalist Spain and the Spanish authorities told him he was to remain in Spain as a virtual prisoner. Then he suffered a freak accident. He had gone out with a doctor friend to visit a newfangled pumping station and was struck in the chest by one of the mechanical arms of the pump. The accident sent him into a coma for three days and nearly cost him his life. When he recovered he faced a terrible situation; he was unable to continue on his mission. So he decided to make the best use of his time of confinement by confirming his previous measurement of the latitude of Barcelona. From his hotel terrace he spent the winter of 1794 conducting astronomical measurements—another 10,000 of them—all to verify his previous value for the latitude of Barcelona.... And this time he got a different answer!

Méchain tried everything to explain the discrepancy. He corrected for every factor he could think of. But the discrepancy remained. How could he now return to France and inform his colleagues that the meter might be "this" long or it might be "that" long? Back in Paris several of his scientific friends—Lavoisier among them—had gone to the guillotine. One scientist had even been thrown in jail for falsifying data (though, it must be said, he had also allied himself with the wrong political party). So Méchain made a fateful choice, he decided to keep the knowledge of this discrepancy secret. But this decision weighed on his mind.

Then, worse, Spanish policy changed and Méchain was obliged to leave Spain—which meant he could not resolve the difference with further observations. He first traveled to Italy and then after a year there, returned to southern France—supposedly to continue his mission. But Méchain had no stomach for the mission. His secret had begun to torture him. He began


Delambre

to slow his pace, making almost no progress, hiding himself away in the mountains of southern France. His letters to his colleague Delambre became dark and fraught with foreboding. He appeared to be on the brink of madness and suicide. Reading between the lines, now, after the fact, we can see where time and again Méchain half-confesses his guilt. But he never admits that he had discordant data.

Delambre and his colleagues were confused. They were desperate to see that Méchain complete his mission and return with the rest of his triangulation data. Yet Méchain refused to return to Paris and refused to send them copies of his latest data. At last his colleagues hit on an ingenious solution. They sent his wife down to fetch him. This was a stroke of genius because Madame Méchain was capable woman and a competent astronomer in her own right. She had assisted her husband with his observations before the Revolution. She agreed to travel to southern France and get her husband back on track—but she had one request in return. She wrote to Delambre in the strictest confidence.

Paris, 30 Mai, 1798

Monsieur,

You engage me to induce my husband to put the final touches on the important work with which you are conjointly charged. No one takes a greater interest in this than I, and I have long considered joining him myself, so that I might bring him words of consolation and peace . . . .

I have told him emphatically not to accommodate me by proposing a rendezvous in a town appropriate to a lady. I will not waste even a quarter-hour of his time because he does not have the time to waste. I have told him that I will gladly meet him on the mountain tops, sleep in a tent or stable, and live on cheese and milk; that with him, I will be content anywhere. I have told him that we will work together by day, and let the nights

suffice for conversation. I am hopeful that the esteem and absolute trust he places in me will allow me to dissipate the unwholesome thoughts which devour his spirit, and which, against his will, distract him from his purpose. When I am done with him, he will be ready to be delivered into your hands . . . .

This, regrettably, is all that it is in my power to do, my final effort for the good of the service, for the interests of my husband, and for glory. Needless to say, all of this must remain between you, me, and Monsieur Borda, who entirely approves of this plan. For all the world, I beg you keep this secret. I have announced that I am going on a visit to the country and no one knows the purpose of my voyage, so as to give no one grounds to say, "She has gone to fetch her husband . . . ."

I have the honor to be, with feelings of the highest esteem, your very humble servant,

—Madame Méchain [10]

Though none of the official records of the expedition mention her name—as she insisted—it is clear that Madame Méchain assisted her husband in the measuring of the final triangles that completed the mission. Then, not long thereafter, Méchain met up with Delambre in Carcassonne, from which they both returned to Paris to a hero's welcome. But Méchain still did not let his colleagues know about his unreported data. The international conference calculated the meter using his original data from Barcelona, and Méchain's additional data was never built into the standard platinum bar. Yet that was not the only "error" made by the august international conference.

Indeed, as happens so often in science, it is the unexpected "errors" which prove most fruitful. As Enrico Fermi once said (and here I paraphrase): "If you make an experiment that confirms your theory, you have made a measurement. But if you make an experiment which disagrees with theory, then you have made a discovery." In their drive for precision, the astronomers had discovered something quite new: that the earth was more lumpy and misshapen than they thought. They had discovered that the earth was not only not a sphere (as they already knew), and not only flattened at the poles (as they already knew), it was (they now discovered) not even a curve of revolution. Each meridian was unique, and each portion of the curvature varied in a slightly irregular way. This was a genuine discovery—albeit one partly suspected before the mission began—and it launched the modern science of geodesy. Ours is not a perfect earth, but an earth made in time, by geological processes over many millennia. There was only one problem: this discovery invalidated the entire premise of the mission. The astronomers had been sent out to measure a portion of the meridian so that it could be extrapolated to the whole quadrant and thereby used to create a universal measure. But because each segment of the meridian had a changing curvature it was not in fact possible to make such an extrapolation. In the end, the scientists assembled in Paris had to use fifty-year-old data to get an approximation of the earth's size, an approximation that they knew to be inadequate.

Only then, after the meter had been decreed and enshrined in its platinum bar, did Méchain decide to take a second trip to Spain. No one knew why he was leaving. Why would a man of sixty, at the height of public acclaim, the director of the Observatory and France's most illustrious astronomer, leave his family again? Today we can guess at the reason. Méchain was travelling south to extend the meridian measurements beyond Barcelona to Mallorca in an attempt to circumvent his original false readings. And again, everything went wrong: war broke

out, as did a yellow fever epidemic. The entire expedition was something of a suicide mission, and Méchain died of malaria on the Valencia coast in 1804. And only then did his papers—those loose scraps of paper and the missing data from the second winter at Barcelona—fall into the hands of his colleague Delambre, who now faced a fateful decision of his own: should he reveal the error to the public, or continue the cover-up?

By this time Delambre had a new tool with which to comprehend error. The irony of this story is that Delambre and Méchain's mission—along with its attempt to push precision to a whole new level—helped scientists conceive a different way to treat error. The mathematician Legendre, one of the members of the international committee which had analyzed the original data from the mission, had been stewing over the data for the past five years. Was the newly discovered lumpiness of the earth due to poor data or was it an actual physical phenomenon? Legendre hit on a way to clarify the question. He showed how one might calculate the best possible curve by selecting a curve which minimized the square of the deviations of the data from that curve. This also implied a different way of approaching error. Within a few short years, in the hands of Laplace and Gauss, it would become a method for managing and taming error, by treating error as a probabilistic distribution. Already in 1807 Delambre was able to use this new approach to come to terms with what Méchain had done.

To Méchain measurement mattered. Precision was his obsession, and error represented a moral failure. He had been sent out to measure the meridian, and his honor and reputation depended on his getting the most exact results possible. To err may have been human, but those investigators who studied nature's perfection had to try to match the perfection of the One who had created nature in the first place. Méchain, like Newton, was a "savant," a natural philosopher for whom science was an attempt to uncover God's perfection, the comprehension of which was not necessarily for public perusal. A savant made judgments. His data were his own. Which is why Méchain did not feel obliged to share all his data, not even with the members of the international committee.

This is quite different from the modern professional scientist's understanding of his duty. Delambre knew what he owed his colleagues—and the French state, which had, after all, sponsored this elaborate mission. He kept his records like a public servant, open for examination. The mission was an early instance of Big Science, a publicly funded research project that took seven years to complete and consumed more than three times the budget of the entire Academy of Sciences. It was a project which had been launched to demonstrate the utility of science to a new kind of state: a republic dedicated to the general good. But with that mission accomplished, and the meter bar safely stored into its triple-locked box, Delambre decided to keep Méchain's cover-up covered. While he published some of the records that Méchain had suppressed, Delambre did not make public Méchain's attempt to suppress the data, nor Méchain's fudging efforts to make his data look better, more precise, than they really were.

But while Méchain had suppressed his data because he thought it mattered, Delambre suppressed the results because he understood that they did *not* matter. Delambre understood that once the platinum bar had been promulgated as the standard—and everyone agreed to it—the meter could not be "wrong." The meter was the meter, and it would only defeat the entire purpose of the standard if scientists were to alter its length every

time new data came in. And so the meter has remained the same length even as scientists have changed the way that the meter's length has been defined. Today, the meter is defined as the distance traveled by light in one 299,792,458^{ths} of a second. That value has been chosen so as to preserve the old original erroneous calculation of the distance from the north pole to the equator conducted by Delambre and Méchain in the years of the French Revolution. In that sense, theirs was not so much a measure for all people for all time, as "an error for all people for all time."

Thus, in the end, the meridian mission had made the meter "universal" even though the definition—and the calculation itself—were arbitrary. The meter could belong to everyone because it belonged to no one. Had the French Revolutionaries simply declared the meter to be some traditional length, I do not think so much of the world's population would be using it today as their measure. So in this sense it does not matter that the meter is "wrong." There is no reason to impugn the metric system, nor the men of integrity who carried out this mission. We need not alter Olympic swimming pools nor revoke gold medals. The success of the expedition, as Delambre understood, was as much political as technical.

The scientists who created the metric system conceived of it as a political tool. These scientists were not simply content to describe the world. Their science—and the metric expedition—was an attempt to actively intervene in the world and change the way people thought. The metric system was designed to give all the world's peoples a common language to describe the most basic objects of their material life. This would allow citizens to trade openly and transparently, transforming all of France—and ultimately the entire world—into a free market for the exchange of goods and services.

The scientists were democrats and economic liberals. They wanted a measurement system that was easy for ordinary people to use—with decimal division to aid calculation—because, as Condorcet put it, only when people could calculate their own best interest could they be really free. In the end, the metric system was to make the French into a "calculating people."

That was why the scientists took decimalization to all aspects of human life, including time. If the Revolution was a call to design the world anew, then time should begin anew too. Thus they introduced a ten-hour day, with each hour divided by one hundred minutes of one hundred seconds. And they introduced a rational calendar of thirty-day months (with a five-day holiday at the end), with ten-day weeks.... (And some have said the main reason the Revolution failed was that they instituted a ten-day wait for the weekend.) As we all realize, these calendar reforms failed. But what surprised the French scientists was the metric system also met with such violent opposition.

This debate over the metric system was the world's first debate over globalization. Debates about globalization today typically pit those who argue on behalf of increased trade as the best way to bring greater wealth and opportunity to the greatest number of people versus those who argue that international trade brings local hardship, costing jobs and disrupting the traditional life by which people have long gauged their happiness and social peace. Exactly the same debate erupted over the metric system.

Most citizens of Revolutionary France recoiled from the scientists' vision. I think Americans are well-suited to appreciate that it is not easy to give up one's habitual system of measures. After all, measurements define our communities, they mark who we are willing to trade with.

Preserving a circumscribed community of measures had a practical economic rationale in Old Regime France; local measures protected small-town business people from price-cutting by big-city traders. And the citizens of Revolutionary France were being asked to make an even more profound shift. That is because their old measures were not the modern kind of units. Their measures were often anthropometric; that is to say, derived from human scale. This is not to say that the "foot" was the length of a human foot. It meant something far more profound. Measures in the Old Regime were often derived from human labor. Vinicultural land was not measured in square feet, but in days: How many days of labor did it take to harvest the grapes? Or a field of wheat might be measured in bushels: How many bushels of grain did it take to sow the land? Far from being irrational, these measurements were very helpful to peasants who worked the land. They were less advantageous to landlords who want to increase productivity. And if you think there is no difference between that kind of measurement and the modern kind, there are five hectares in Florida I'd like to sell you.

What's more, the old diversity of measure actually greased the wheels of commerce. That is because France operated on what we would call a "fair price economy." Prices for basic foodstuffs, like bread, were fixed, and woe to the baker who dared to charge more than, say, three *sous* for a loaf. He risked being hauled across the counter and strung up from the nearest tree. So what did the unfortunate baker do when the cost of flour rose? He did not increase the price; he shrunk the loaf. This was acceptable to his customers (within limits) because everyone could still afford a loaf at three *sous*. It is not that his customers were unaware of his ruse, but that they were satisfied that the core principle of equity had been upheld: everyone could still afford a loaf. The same ploy can still be found when candy bars are shrunk so that kids can afford a bar. That is why a pint of beer was smaller in Paris than in Saint-Denis, because as everyone knows, life is more expensive in the big city.

In sum, measures in the Old Regime, unlike our measures today, expressed quality as well as quantity. A community's measurements express its values. And however confusing they might seem to us, they formed the backbone of the economy of the Old Regime.

That is why so many French people objected fiercely to the metric system. At one point, the French government had to send in government troops to confiscate the old measures from the Paris marketplace. And even this was not enough. In the end, the government retreated from its plans and Napoleon Bonaparte, who had once praised the metric system as a creation that would outlast conquests, rescinded the metric system in 1812. Now he scorned the scientists' grand ambitions. "It was not enough for them to satisfy forty-million French people," he sneered, "they wanted to sign up the whole universe."[11] Not for another thirty years, until the 1840s, did France reinstate the metric system, and even then it took another century to achieve full conversion throughout the nation.

So what about the United States? Why hasn't America yet adopted the metric system? If Thomas Jefferson had had his way, we would have been the second nation to adopt the metric system. Jefferson was in close contact with Condorcet and the other leaders behind the metric legislation. But he was extremely annoyed by the French decision to choose a meridian that ran through France alone. As he put it: "We will have to take their word for it."[12] And then his proposal for a metric system was rebuffed in Congress. The reason for this seems clear. As the cre-

ation of a single colonial power, America already had relatively uniform weights and measures up and down the Atlantic seaboard—at least in official use. But this meant the nation had less incentive to switch to a new system. Moreover, as Jefferson noted, the American government tended not to interfere in such matters. When later in his life, Jefferson was asked about this matter by John Quincy Adams, then contemplating a proposal to have the U.S. join the metric system, Jefferson wrote back:

On the subject of weights and measures, you will have, at its threshold, to encounter the question on which Solon and Lycurgus acted differently. Shall we mould our citizens to the law, or the law to our citizens?[13]

So America has stuck with the old Anglo-Saxon . . . until recently. Today there is pressure from global industries to go metric. Automobiles, alcohol, bicycles are all sized in metric units. Even Coca Cola is now being sold in two-liter bottles. And the pressure will continue to build, even in as large an economy as the American one. Already American scientists and medical personnel use the metric system, and most (but not all) engineers. But this means that for the first time in its history the U.S. has two functioning systems of weights and measures in regular use: the Anglo-American system and the metric system. The result has been such disasters as the crash of the Mars Climate Orbiter. But I think I can safely predict that it will be many decades before the rest of the country switches to the metric system in daily life. After all, it has taken many decades wherever the metric has been introduced.

Notes

[1] Ken Alder, *The Measure of All Things: The Seven-Year Odyssey and Hidden Error That Transformed the World* (New York: The Free Press, 2002).

[2] Louis-Sébastien Mercier, *Le nouveau Paris* (Brunswick, n.p.: 1800) 3:44.

[3] Arthur Young, *Travels During the Years 1787, 1788, and 1789* (Dublin: Gross, 1793), 2:43–44.

[4] For the number of measurement units, see Ronald Zupko, *French Weights and Measures Before the Revolution: A Dictionary of Provincial and Local Units* (Bloomington: Indiana University Press, 1978), 113.

[5] Archives de l'Académie des Sciences, Paris, Fonds Lavoisier 1229(2), Lavoisier to Méchain, [mid-June 1793].

[6] Jean-Baptiste-Joseph Delambre, ed., *Base du système métrique decimal, ou mesure de l'arc du méridian compris entre les parallèles de Dunkerque et Barcelone, execute en 1792 et années suivantes, par MM. Méchain et Delambre* (Paris: Baudouin, 1806, 1807, 1810).

[7] Karpeles edition, Santa Barbara, California: Delambre, *Base du système métrique decimal*, 1:title page.

[8] Archives de l'Observatoire de Paris, Paris, E2–9, Delambre's final comments in Méchain's notebook, c. 1810.

[9] Dibner Library, Smithsonian Institution, Washington, DC, MSS420A, Delambre to [Calon], 27 frimaire V [17 December 1796].

[10] Archives de l'Observatoire de Paris, Paris, E2–19, Mme. Méchain to Delambre, 11 prairial VI [30 May 1798].

[11] Napoléon, *Mémoires pour servir à l'histoire de France sous Napoléon, écrits à Sainte-Hélène*, Gaspard and Charles-Tristan Montholon, eds. (London: Bossagne, 1823–24), 4:211–15.

[12] Thomas Jefferson, "Memorandum to James Monroe," before 4 April 1792, in Jefferson, *The Papers of Thomas Jefferson*, Julian P. Boyd, ed. (Princeton: Princeton University Press, 1950-), 27: 818–22.

[13] Thomas Jefferson, to J. Q. Adams, 1 November 1817, in Jefferson, *The Writings of Thomas Jefferson*, H. A. Washington, ed. (New York: Derby and Jackson, 1859), 7:87.

Illustrations

PAGE 5: This map shows the triangulation of the Paris meridian during the expedition of 1792–98. Delambre's portion ran from Dunkerque to Rodez, and Méchain's portion ran from Rodez to Barcelona (Mont-Jouy). Two baselines were measured: one at Melun, near Paris; the other outside of Perpignan. Map by Chris Robinson.

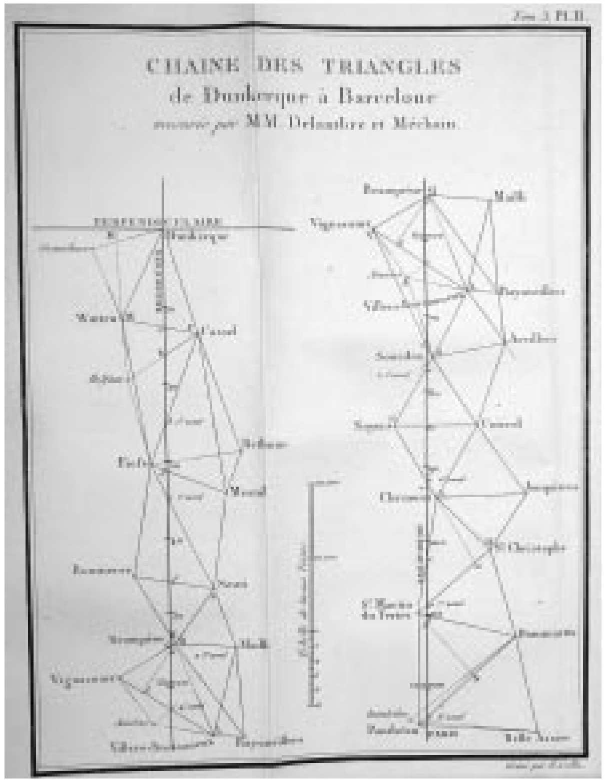
PAGE 6: The Borda circle, invented by the physicist and naval officer, Jean-Charles de Borda, was first used during the meridian expeditions of the revolutionary years. Its great advantage was its combination of portability and precision, which it achieved by enabling the observer to repeat the same observation many times without resetting the zero. It is here shown in its horizontal configuration for measuring the angle between two geodetic sites. It could also be used in a vertical configuration to measure the height of astronomical bodies. From J.-B.-J. Delambre, *Base du système metrique décimale* (Paris, 1806–10), vol. 2, plate VII.

PAGE 9: Pierre-François-André Méchain (1744–1804) in the uniform of the Academy of Sciences, as painted posthumously in 1824 by Narcisse Garnier, based on etchings taking during Méchain's lifetime. Photo from the Musée de Laon.

PAGE 10: Jean-Baptiste-Joseph Delambre (1749–1822) at age fifty-two, as painted in 1803 by Per Eberhard Gogell. Delambre wears the uniform of the Academy of Sciences, of which he was the Permanent Secretary. From the Swedish Royal Academy of Sciences. Photo by Georgios Athanasiadis.

PAGE 23: Letter from Dibner Archives, MSS420A. Jean-Baptiste-Joseph Delambre to General Etienne-Nicolas Calon (director of the Dépôt de la Guerre), *27 frimaire V* [17 December 1796]. Delambre's letter is mostly a plea that Calon supply him with additional funds so that he may continue the meridian expedition. During this period of hyperinflation, the cartography department of the French army was the main sponsor of the expedition.

PAGE 36: This detailed view of the triangulation of France shows the sector that ran from Dunkerque to Paris, as measured by Delambre. From J.-B.-J. Delambre, *Base du système metrique décimale* (Paris, 1806–10), vol. 3, plate II.



COLOPHON

The text of *The Measure of the World* was composed in *Fournier*, a typeface produced by Monotype Corporation in 1925 as an inspired version of types cut in eighteenth-century Paris by Pierre Simon Fournier. His older brother, Jean Pierre, was famous for his purchase of France's historic *Le Bé* typefoundry in 1730. However, Pierre Simon *'le Jeune'* was famous in his own right as a master punchcutter and his detailed treatise on typefounding, *Manuel Typographique* (1768). *Fournier*, very much admired for its elegance, is a compact yet open typeface with its companion italics based on eighteenth-century handwriting.