Chapter 1

Measurement Before The Metric System

In 1668, The United States did not exist, but measurements did. They existed in as many versions as one might imagine grains of sand on a beach. They were brought by settlers who came to North America, and reflected the local customs found in their place of origin. One might measure with a flemish ell, or English ell, or whatever the ell could be agreed upon. There was a notion of being fair with measures, but no concept of defining a single set of measures to which all would adhere in trade.

Location	**Divisions**	**Length**
Hamburgh	8 Parts	23.2 mm
Austrian	8 Parts	25.8 mm
Italian	8 Parts	28.3 mm
Bremen	10 Parts	23.7 mm
Swedish	12 Parts	24.3 mm
Turkish	12 Parts	31.3 mm
Bavarian	12 Parts	24.0 mm
Spanish	12 Parts	23.0 mm
Portuguese	12 Parts	27.0 mm
Moscow	12 Parts	27.7 mm
Russian	8 Parts	44.1 mm
Amsterdam	12 Parts	23.5 mm
Rhynland	12 Parts	26.1 mm
English	32 Parts	27.0 mm

Table 1.1: Table of Various Archaic Inches Expressed in mm

In 1668 England, there were also a number of measures, which were marginally defined. The base unit was the barleycorn, and three in a row, laid end-to-end, were defined as an inch. Elsewhere, the inch was defined by the width of the thumb, or in some other ad hoc way which became the tradition. The inch as defined by the Anglo-Saxon compromise of 1959 is 25.4 mm. Table 1.1 presents a few examples of the various inches, which have existed over the years, expressed in millimeters. Not only do the lengths of the various inches vary by almost a factor of two in one case, but they are also divided differently. Provincial Italian lengths for the foot ranged from 295 to 590 millimeters, and those of pre-metric France extended from 248 to 357 mm. A large number of uncoordinated volume and weight measurement designations also existed.

One man who was interested in languages, and all things scientific, would offer a way to eliminate this vast spectrum of measurement designations. His name is John Wilkins (1614-1672), and he would invent the metric system.

John Wilkins was passionate about disseminating scientific knowledge to as many people in the general public as possible. His target audience were people who would not normally be exposed to a scholarly view of technical subjects. In order to convey this knowledge to as large an audience as possible, he always wrote in English instead of Latin.

Early in his career, Wilkins wrote two volumes called *The Discovery of a New World* (1638) and *A Discourse Concerning a New Planet* (1640). They explained and defended the sun-centered Copernican view of planetary orbits, and also argued that other planets and bodies in the heavens were like our own in substance. This meant that the heavens obeyed the same scientific laws that apply here on earth. The purpose of these writings was not only to discuss the Copernican system, but to also erode the uncritical veneration of ancient authorities among the populace.

There were two printings of *The Discovery of a New World* in 1638. In 1640, the book was reissued after Wilkins added a chapter, and made a small number of changes to the text. *The Discovery of a New World* was widely read in Britain and was translated into French in 1656. Later in 1713 Wilkins astronomical works were translated into German.

The scientific works of John Wilkins were greatly influential on the astronomical views of the time. When Michael van Langren (1598-1675) used his observations of the moon to create a lunar map, he named one of the craters after Wilkins.

In 1648, Wilkins wrote a work that was more clearly meant to be a scientific exposition for members the general public. It is called *Mathematical Magick, or the Wonders that May be Proved by Mechanical Geometry.* In this work, the principles of mechanics were expounded upon for use by the common person, with the hope that the new mathematical approach to mechanics might be adopted by him. Practical examples were offered by Wilkins to help convince his target audience of the utility of this viewpoint. This was a direct challenge by Wilkins to mathematicians and others who would hoard their technical knowledge. In his youth, Isaac Newton (1642-1727) read *Mathematical Magick*, and was greatly impressed with it.

Wilkins wrote a work which has a section on ciphers and cryptography, which demonstrates his budding interest in languages. He saw the diversity of languages, along with the use of different symbols for writing them, as obstacles to the dissemination of knowledge. Wilkins envisioned a "Universal Character to express things and Notions as might be legible to all People and Centuries, so that Men of Several Nations might with the same case both read and write it." [1]

It was believed by Wilkins, that it was possible to create a universal set of characters and language, which could be understood universally. This would remove language barriers between peoples and allow the free flow of knowledge to occur. It would also replace Latin, which was losing its universal appeal as the language of philosophy. How this might be accomplished would be of interest to Wilkins until his death. In the seventeenth-century, the notion of a universal language (also called artificial languages) was widespread throughout Europe.

Wilkins was an amiable person who was able to embrace, gather, and nourish exceptional scholars of many different disciplines, views, and temperaments. The group of people he gathered together at Oxford would later coalesce to form The Royal Society in London.

On November 28, 1660, The Royal Society flickered into existence, when John Wilkins and others met to discuss the creation of a scientific society. Wilkins was appointed the chair for this historical gathering. In 1662, the society was incorporated, and The Royal Society began in earnest.

The Royal Society requested that Wilkins undertake the development of a universal standard of measure. [1] John Wilkins, William Brouncker (1620-1684), and Christian Huygens (1629-1695) worked together to investigate a suggestion by Christopher Wren (1632-1723), that a measurement standard could be derived from the motion of a pendulum.

The system Wilkins proposed was based on a high tech device of the day: the seconds pendulum. The pendulum was first studied by Galileo Galilei (1564-1642) in 1602. Pendulums were found to have a constant time oscillation, and therefore can be used to accurately measure time intervals. They were the key to creating the first major improvement in timekeeping since antiquity. Dozens of designs for pendulum clocks followed. The time a pendulum takes to swing back and forth, is essentially dependent on its length. This meant that a pendulum with a one second period would have its length defined by the astronomical clock in the sky.

Wilkins proposed that one could construct a simple pendulum, (i.e. a *seconds pendulum*), with a one second period, and use it for a universally defined length. Now that a length had been established, which was tied back to the scientific phenomenon of the second, one could then subdivide this length by ten. Wilkins proposed making a box from this smaller division of the primary length and use it to define a volume. He then proposed it be filled with water, and this weight used as a universal value for the comparison of weight.

A length standard which is very nearly the length of a seconds pendulum would later become known as the meter. One-tenth of the length of the meter is 100 millimeters. When a cube is constructed with 100 mm sides, the volume it contains would become known as a liter. When this cube is filled with pure water, the mass is very nearly the mass known today as the Kilogram.[1]

It was hoped the combination of a universal language and writing method, with a universal measurement method, would allow scholars from around the world to share their work universally. Wilkins elaborated upon his new language and measurement system in a book entitled: *AN ESSAY Towards a REAL CHARACTER, And a PHILOSOPHICAL LANGUAGE.* Within this book, are a few pages in which he defines a new universal measurement system. Wilkins' had his work published by

[1]Metric quantities with magnifying prefixes, such as Kilo, Mega, Giga, Tera and so on, will be capitalized (e.g. Kilogram, Megameter, Gigajoule, Teraliter). Metric quantities with reducing prefixes such as milli, micro, nano, pico and so on will be rendered in lower case (e.g. millimeter, microgram, nanoliter, picojoule). A capital K will be used as the metric prefix symbol, so Kilometer will be abbreviated Km.

the Royal Society on Monday April 13, 1668. This is the day the metric system was born.

Wilkins' *Essay* was received with great interest, and a number of scholars continued to work on expanding Wilkins' ideas following his death. Isaac Newton had attempted to create a similar artificial language, and commented on Wilkins work in a letter to John Locke (1632-1704). Italian physicist and mathematician Giovanni Borelli (1608-1679), Christian Huygens in the Netherlands, and German mathematician Gottfried Leibniz (1646-1716) all obtained copies of Wilkins' *Essay*. There were efforts to translate the work into French.

Wilkins' Biographer, Barbara Shapiro, indicates that his *Essay* had lasting intellectual interest:

> Wilkins's *Essay* continued to attract serious attention in the nineteenth and twentieth centuries. Erasmus Darwin praised it, as did the pioneer anthropologist Lord Monboddo, in his *Origin and Progress of Language* (1809). The philologist A.J. Ellis, author of the *Alphabet of Nature* (1845), acknowledged his indebtedness to Wilkins. Max Müller, also writing in 1845, said that Wilkins's universal language proved the best solution to the problems with which it dealt presented up to that time. Roget, author of the still popular *Thesaurus,* expressed his indebtedness to Wilkins and modeled his classifications on those of his predecessor. More recently, Wilkins's work has come to the attention of those concerned with the development of symbolic logic and semantics. The *Essay* has also been recommended to librarians wrestling with the problem of classifying scientific documents. . . .[1]

It is a minor historical mystery as to whether Wilkin's work was consulted by those who began the development of the modern metric system. If it was not, it would be a considerable coincidence that an identical system would have been developed independently. One reason Wilkins is not more discussed in the history of science, is that many of his ideas have been long ago incorporated into the scholarly world, and their origins not well acknowledged. Wilkin's proposal for a universal measure was very possibly so ubiquitous, that it was considered a default idea.

It is almost a certainty that Wilkin's idea for a Universal Measure was the basis for the development of the metric system when it was conceived. In 1805, a contributor to the *Philosophical Magazine* wrote a letter to complain that Wilkins did not receive the credit he should in England for the creation of the metric system. He further grumbled that the French have not acknowledged the creation of the system by Wilkins, and this omission, he suggests, is probably wilful. The contributor quotes from the French *Encyclopedie* which asserts that Gabriel Mouton (1618-1694) was responsible for the creation of the metric system based on the Earth.[2] Mouton also considered using a pendulum as a length standard, but what he proposed was not a seconds pendulum. Wilkins discussed using the Earth, barometric pressure measurements, and a seconds pendulum and settled on the latter. It may be difficult to decide who thought of these ideas first, but we know who published first, it was John Wilkins, and unlike Mouton, Wilkins proposed an integrated measurement system.

The Proposal for a Universal Measure contained in Wilkins' book, is essentially the system part, of what in the United States is generally called The Metric System, although the modern version is officially known as the SI. The length of the seconds pendulum is the original candidate for the length of a meter. The square container constructed from one-tenth of this length is now known as a liter. When filled with water, its mass is the Kilogram. We know that the metric system was invented on April 13, 1668 because Wilkins published it on that date. The decimalization of this system would come later.

General Washington (1732-1799), with the support of the French Military, and the French Monarchy, was able to secure independence for the American colonists, and usher in the creation of The United States of America.

In his first State of The Union Address, in January of 1790, George Washington saw three important topics which he asserted were in need of immediate attention by Congress. The first two were defense and the economy. The third topic was the establishment of uniform weights and measures in the country. Washington stated: "Uniformity in the currency, weights and measures of the United States, is an object of great importance, and will, I am persuaded, be duly attended to."

He returned to this topic in his second address, "The establishment of . . . standards of weights and measures, of the post office and post roads, are subjects which I presume you will resume of course, and which are abundantly urged by their own importance."

Washington would have to once again address the subject in his third annual address, "... uniformity in the weights and measures of the country is among the important objects submitted to you by the constitution, and if it can be derived from a standard at once invariable and universal, must be no less honorable to the public councils than conducive to the public convenience."[8] The President's description of an "invariable and universal" measurement system echoed the vision Wilkins proposed, and that SI would become. Washington implored, and congress ignored.

In New York, traders were purchasing cloth by the English ell (nearly a yard), and selling the same cloth in lengths of the Flemish ell which was about half the length. Disputes occurred in the grain trade, where purchasers would use a larger 1/2 bushel measure than sellers 1/2 bushel to purchase grain, and refuse to change the per bushel price.

A central player during the creation of the metric system is Thomas Jefferson (1743-1826), a consumer of waffles, enjoyer of coffee, sage of Monticello, and voracious reader. When Jefferson began his life, he was a British subject. When he last looked over the verdant canopy of trees surrounding his estate at Monticello, he was a United States citizen. Thomas Jefferson was in agreement that US weights and measures required attention. His sense of democracy was incensed by the weights and measures fraud occurring in US commerce. There should be one single set of weights and measures for America.

The weights and measures of France were also in complete disarray. There were perhaps 250,000 different measurements in use at that time in France. Jefferson was in close contact with The Marquis de Condorcet (1743-1794) who wanted to divorce measurement from body parts and give them an objective scientific foundation. Condorcet proposed that the length of a seconds pendulum should become the base unit for a new scientific system of measurement. Jefferson thought the situation over, and became an advocate of using a seconds pendulum as a length standard. He convinced James Madison (1751-1836), who in turn lobbied James Monroe (1758-1831) in 1785. There was also a proposal in Britain to use the seconds pendulum as a standard length.

Jefferson saw the seconds pendulum as the key to a common universal length. After discussions with clock makers, he was persuaded that the use of a rod for the pendulum would produce a more uniform length standard. One Summer Jefferson dedicated himself to the creation of a new set of weights and measures. Andro Linklater describes it in his work *Measuring America*:

> In less than 1000 words, he then outlined the first scientifically based, fully integrated, decimal system of weights and measures in the world. Its basic measure of length, derived from the seconds rod, was a foot, which would be divided into 10 inches. A cube of rainwater, whose sides were 1 decimal inch long, was to weigh 1 decimal ounce, and 10 of these ounces would make 1 pound. The basic unit of capacity would be the bushel, which was to measure 1 cubic foot, that is to say, 1,000 cubic inches." [3]

One can clearly see the echos of Wilkins' Universal Measure and the metric system in this scheme. Jefferson even used square containers, which could be easily replicated by any citizen, in case of a metrological dispute. He also eliminated any distinction between wet and dry measures. Was Jefferson influenced by Wilkins, or was this a scientific idea which was ripe to emerge from the scientific zeitgeist of the era?

Alexander Hamilton (1755(?)-1804) also was in favor of Jefferson's system of weights and measures. It was felt by proponents of this system that if Congress did not take up this scheme quickly, it might be tabled and then become neglected indefinitely. This concern proved to be correct and Congress never addressed Jefferson's proposal.

Jefferson's arguments for a measurement system which is simple and accessible to all people—independent of their educational level—were also embraced by the creators of the metric system. The paramount question was how they would determine the base unit of length. Would it be the seconds pendulum, or the length of two different Earth measurements? These were the alternatives proposed by the French during the development of the metric system.

In September of 1790, it appeared the second pendulum was going to be the standard, and preparations were made to fabricate one. The French Academy reopened the discussion on February 16, 1791 in response to a proposal by Jean Charles Borda (1733-1799). A report was issued. Over and over in the French report on the choice of a standard for length, they emphasized the utility of a seconds pendulum. Then, to the surprise of Jefferson and others, the length of a meridian was chosen as a standard to produce the base length of measurement for the metric system. There was no explanation offered to justify the rejection of the seconds pendulum, which had been the preferred standard for a unit for many decades.

The choice of the Earth as "measurement standard" seems at odds with a scientific definition and absolutely assaults reason from an engineering perspective. The seconds pendulum is a device which can be contained in a completely controlled environment. It could be independently replicated by other nations. Jefferson had already attempted to improve the accuracy of the device by using a rod for the pendulum. Improvements in mechanical measuring devices during this period were everywhere in abundance. John Harrison (1663-1776) revolutionized the design of clocks and solved the problem of determining longitude. Engineering and science rely on repeatable experiment, no less than metrology. The seconds pendulum could be studied by all nations, and improved as technology allowed. The length of a meridian through France and Spain was only accessible if the political climate of the period allowed access to this geographical area.

The length of the meridian had already been measured twice, but as one of his last acts as King, Louis XVI agreed to repeat the endeavor. Soon after, The French Revolution took hold, so why would those involved in a revolt against the Monarchy agree to continue what the deposed monarch had approved? Andro Linklater suggests that Monge had it in his mind that time would be decimalized in the future, and therefore the second would need to be changed. The seconds pendulum length would be based on the "old second" and could become a roadblock to his idea of future reform. There is another possibility. It could have been that because of Wilkins' work, the seconds pendulum was seen to be British, and the metric system was to be based on French notions. The choice of the meridian, rather than the pendulum allowed for a bit of a smoke screen about the British origin of the metric system, even though the definition of the liter and Kilogram would remain those defined by Wilkins. Politics prevailed, and the meridian would be used to determine a length standard.

Another contributing factor may also have been at work. Lagrange and Condorcet both had expressed their preference for the seconds pendulum. In September of 1775 Lagrange wrote a letter to Condorcet in which he argues for the seconds pendulum: "I doubt however that we can find anything more suitable." Talleyrand proposes the use of the seconds pendulum on March 9, 1790, and Condorcet is also still in favor of its adoption.

In 1791 Lagrange and Condorcet both contributed to the report, which concludes that the length of a meridian arc should be used as the standard. What had changed? The triangles that would be used for the arc would be on the surface of a sphere. This was a complicating factor. But in 1787, Legendre proved a theorem that allowed him to treat spherical triangles as plane triangles. On March 7th of 1789, Legendre revealed his discovery to his colleagues, which were published by the French Academy. Ruth Inez Champagne asserts: "The recommendation to measure the length of the meridian arc is based on the academicians' desire to develop more precision in geodetic measurements.[4]

The abandonment of the seconds pendulum by the French was unacceptable for Thomas Jefferson. The core idea that the metric system was to be a universal measure available to all nations became a humbug in his eyes. It was an act of French nationalism. The weights and measures of the new American Republic would continue to be neglected by congress, as was the metric system.

Although the seconds pendulum was no longer the preferred standard of length, The French Academy decided to continue determining its value in Paris. The Academy may have decided to determine this length in case the measurement of the meridian was interrupted or terminated.

It took seven years for Jean-Baptiste-Joseph Delambre (1799-1822) and Pierre-Francois-Antré Méchain (1744-1804) to measure the meridian, and indeed if it would happen at all was touch-and-go. The seconds pendulum would provide an option if something went wrong. There was another motivation for the continuing refinement of the length of the seconds pendulum:

> Lagrange also works to prepare a favorable report on Prony's manuscript which suggests refinements to be introduced in measuring the length of a pendulum in order to insure greater accuracy. The mathematicians are still concerned with determining the length of the pendulum accurately since they want to express the length of the seconds pendulum in terms of the meter. By knowing this relationship, the length of the meter could be re-established at any time without a new geodesic measurement.[5]

Clearly if the meter standard were somehow destroyed, taking seven years to reproduce the standard would be prohibitive. This understanding also begs the question as to why they did not adopt the seconds pendulum in the first place.

When the expedition was complete, it became obvious to Delambre that the data taken might not be reliable. It was clear to Delambre that Méchain had suppressed and altered data, but, despite this, had done his best to produce as accurate a result as possible. Méchain also saw fault with the irregularities of the Earth and found other possible sources of error.

The men of that era did not have a modern understanding of systematic and random measurement errors, which raised their expectations of how accurately they might measure the meridian. When discrepancies arose, they did not have the mathematical tools to understand or correct them.

The metric system had plenty of enemies. A scandal might finish the metric system off before it started. The discrepancies that existed were rationalized by Méchain, and the meter defined.[6]

One of the great coincidences of the metric system, is how close the length of the meter, as defined using the meridian measurement, is to the length determined with the seconds pendulum. This fact may have allowed for the political winds to swing from the seconds pendulum to the meridian measurement without considerable objection.

The determination of the length of a seconds pendulum in Paris was undertaken by Borda and Jean Dominique Cassini (1748-1840), and completed long before the length of the meridian had been determined. The seconds pendulum measurement device was constructed by instrument maker Étienne Lenoir (1744-1825). In 1784 he had collaborated with Borda to create the repeating circle, that would be used to determine the meridian.

The seconds pendulum utilized a platinum sphere which was about 38 mm in diameter with a mass of 526.1 grams (9911 French grains). This sphere was suspended with a thin iron wire about 3.7 meters long. Platinum was chosen because of its high specific gravity. It would occupy the smallest volume for a given mass. This in turn would minimize any error introduced by any residual air resistance.

The iron wire was located in front of a pendulum clock, which was to be used as a calibration standard for the period of the seconds pendulum. An airtight case enclosed the device. A glass window allowed for readings to be taken with a telescope. A considerable number of corrections were implemented so that the length of the seconds pendulum in a vacuum would be computed. The length of the wire and sphere were determined using a platinum scale. The scale was fitted with a section of copper which could be used to calibrate out any temperature variation. Corrections were also made for the elongation which occurred from its own weight.

Twenty sets of measurements were obtained by Borda and Cassini from June 15 to August 4th of 1792. Using these observations, the length of the seconds pendulum was calculated to be 994.5 mm (440.5593 lines).[7]

The first aspect of what would become known as the metric system was the establishment of length, volume, and mass standards, which were originally provided by Wilkins. The second attribute is the expression of these values as decimals. The notion of decimals was under investigation by learned men, but early implementations were quite cumbersome. Simon Stevin (1548-1620) devised a method he called *disme* in which he had an integer value called unity, that consisted of 10 primes, the prime in turn consisted of 10 seconds, the second consisted of 10 thirds, the third of ten fourths and continued in this way to describe smaller and smaller divisions.

The notation used for each of these decimal divisions was (0) = unity, (1) = prime, (2) = second, (3) = third, (4) = fourth. The notation continued in this way. The notation was placed above integer values as a superscript. A fraction such as 77 23/100 would become $7\ 7^{(0)}\ 2^{(2)}\ 3^{(3)}$. The fraction 4/100 was written as $4^{(3)}$.

This notation was kludgy and other mathematicians began to refine the idea.[9] Bartholomaeus Pitiscus (1561-1613) simplified decimal notation so that 4/100 ($4^{(3)}$) became 004 or 9/10 ($9^{(2)}$) became 09. John Napier (1550-1617) invented logarithms and utilized the decimal point as a separator with the notation adopted by Pitiscus. A number of alternative representations were put forward, which included the use of Roman numerals as the superscripts in place of Arabic numerals. During the eighteenth-century, European scientists embraced the decimal notation used by Napier, and the others became obsolete. In the US, we write the decimal expression of 4/100 as 0.04 or 9/10 as 0.9 using a period as a decimal marker. This simplified notation was developed just in time to be adopted for the metric system.

Wilkins' proposal for a universal measure is a unique singularity in the history of measurement. From as far back as the fog of pre-history allows us to probe, accepted measurement values were based on ad hoc choices of plant seeds or the lengths of particular body parts.[2] It is immediately obvious from our modern perspective that a large amount of variability would be inherent in these choices. In contrast, Wilkins created and fabricated his own invariable measurement system, using his knowledge of nature. His universal measure, unlike the measurements of antiquity, has a birthday: Monday April 13, 1668.

Wilkins' length, volume, and mass standards were based on the best available science, and in theory would be accurately repeatable. When paired with decimal expression of their numerical quantity, they formed the basis of the metric system. Wilkins' notion was perhaps too radical for the time, as it would be well over a century before a country would adopt and refine these ideas into an accepted measurement system

[2]In the United States, mass is still described in terms of cereal grain. There are 7000 grains in an avoirdupois pound and 5,760 grains in a troy pound. Aspirin, the mass of bullets and their propellant, as well as gold foil in dentistry, are still measured in grains. The foot as a measurement unit is, of course, ubiquitous in the US.

References

[1] Barbara Shapiro *John Wilkins 1614-1672 An Intellectual Biography* University of California Press, 1969, page 47

[2] Unknown Contributor *Philosophical Magazine* Volume XXI, London 1805 page 163-174

[3] Andro Linklater *Measuring America* page 112

[4] Champagne, Ruth Inez *The Role of Five Eighteenth-Century French Mathematicians in the Development of the Metric System* PhD Thesis, Columbia University page 266

[5] Champagne, Ruth Inez *The Role of Five Eighteenth-Century French Mathematicians in the Development of the Metric System* PhD Thesis, Columbia University page 268

[6] Alder, Ken, *The Measure of All Things* Chapter 11

[7] Smeaton, William A.*The Foundations of the Metric System in France in the 1790s* Platinum Metals Rev., 2000, 44, (3) page 125-134

[8] Vera, Hector, *The Social Life of Measures – Metrication in the United States and Mexico, 1789-2004* PhD Thesis September 2011

[9] Zupko, Robert Edward, *Revolution in Measurement – Western European Weights and Measures Since the Age of Science* The American Philosophical Society Independence Square Philadelphia 1990 pp 121-123