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A chronological history of the modern metric system (to 2008)

Throughout all of history there have been people who have given time, energy, and money to help our measuring methods become more rational, sensible, and above all, more honest.

Thanks to these people, gone are many of the countless, daily opportunities for the strong to injure the weak, for the smart to cheat the simple, and for the rich to take advantage of the poor.

Much of this success is due to the system based on a '*universal measure*' that was first described by John Wilkins in London. Go to the article *Commentary on 'Of Measure' by John Wilkins* for a better understanding of how the work of John Wilkins, *AN ESSAY Towards a REAL CHARACTER, And a PHILOSOPHICAL LANGUAGE* (1668), fits into an historical context. Wilkins' *Essay* shows that the metric system and the International System of Units (SI) both had their origins in England in 1668.

The subsequent development of the metric system in France in the 1790s was also heavily influenced by thinkers from the USA, especially Benjamin Franklin (1706/1790), Thomas Jefferson (1743-1826) and George Washington (1732/1799).

The desire for a universal measure was voiced by many scientists and philosophers throughout history. John Wilkins called it a *desiderata*, and Condorcet said that the metric system, based on the *universal measure* of a metre, was *for all people, for all time*. These people knew that a *universal measure* would help trade, communication and science, and by cutting all confusion due to multiple measuring words would foster understanding between people and nations.

Agreed, accurate, and precise measuring standards for length, mass, volume, and time that can be used equally across communities have been a vital need in the development of all societies since the evolution of agriculture and the growth of large scale communities and economies.

Every attempt that has been made to agree on an arbitrary human measure as the standard, such as thumbs, hands, spans, feet, paces ... has always been defeated by the problem of human pride.

It is well known that if three men meet together to decide on a standard foot, then each of them will insist that his foot should become the standard foot. On a larger scale, if three nations meet to agree on a standard foot and each of the three already have feet that are different in length, then even though all three agree that having an agreed standard foot will benefit all of them, the question they ask is, *Which of our leaders will be chosen to have the model for a new standard foot?* Throughout history no-one has resolved this difficulty. **Note**: in 2008, the various states of the USA have yet to resolve whether they will use the international foot or the statute foot; some use one, some use the other, and some use both.

John Wilkins recognised, in 1668, that creating a new, universal measure that was derived from nature was the only way to replace local measures without local disputes. Wilkins' universal measure is now the basis of the modern metric system.

The quantification of land, goods, building materials, and the system for recording the figures are now much easier, more accurate and more precise. This applies to all human activities such as trade, construction, agriculture and ownership.

It is intended that this timeline will give you information about the important dates and events in the development of *The International System of Units* (SI), and also a feel for the life and times at various stages in the history of the metric system and of the SI.

This timeline includes some experiences with the metric system from many nations, but with more details from Australia, the United Kingdom (UK), France and the United States of America (USA). The Australian experience is included as a successful example of metrication, and the UK is included as an unsuccessful example of metric conversion, despite the fact that the concept for a '*universal measure'* first arose in England. France and the USA are included because they are respectively the first and last nations on Earth to legally adopt, promote, and widely use the metric system.

Because of the metric system, the whole world is now able to communicate through common ways of measuring. We can share the same perceptions of space, dimensions, and mass. As an example, when two farmers from two different countries met, they used to find it hard to understand each other when the conversation touched upon miles, arpents, chis, ells, or toises, for each would have different magnitudes in mind, but they understand each other without difficulty when talking of metres, litres, or kilograms.

15 000 000 000 before the Common Era (BCE)

The metric system has given us simple methods to handle very large numbers, very small numbers, and all of the other numbers in between. Here is the biggest example.

The 'Big bang' theory of the Universe is based on the observation that all the stars and galaxies in the Universe seem to be moving away from each other. If you calculate their speeds of separation, you can calculate that the Universe might have begun with a 'Big Bang' 15 000 000 000 years ago. We observe the speeds using light, so 15 000 000 000 light years in each direction indicates that we are at the centre of a sphere with a radius of 15 000 000 000 light-years; it follows that the diameter is 30 000 000 000 light-years. As light travels nearly 9 500 000 000 000 kilometres in a year, this means that the diameter of the Universe is approximately:

30 000 000 000 years multiplied by 9 500 000 000 000 kilometres per year
which equals 285 000 000 000 000 000 000 000 000 kilometres

This is a very large number and before the metric system was developed, people – even scientists and mathematicians – had difficulty saying or writing such big numbers.

These days we simply say that the diameter of the Universe is about 285 yottametres.

Note:

According to NASA (**http://map.gsfc.nasa.gov/universe/uni_shape.html**):

> *We now know (as of 2013) that the universe is flat with only a 0.4% margin of error. This suggests that the Universe is infinite in extent; however, since the Universe has a finite age, we can only observe a finite volume of the Universe. All we can truly conclude is that the Universe is much larger than the volume we can directly observe.*

The calculation above (written prior to 2008)
has been left in as a demonstration of the use of SI for large numbers. ***Editor***

4 500 000 000 BCE

The Earth formed as part of the solar system.

200 000 BCE

The first traces of humans appeared on the Earth.

5000 BCE

The earliest known reasonably uniform methods of weights and measures seem to have arisen some time after 5000 BCE. These appear to have been used by the people of Egypt, Elam (now in Iran), Mesopotamia (now in Iraq and surrounding areas) and the Indus Valley (now parts of India and Pakistan).

These societies used measures for many tasks: trading for food, designing and sewing clothes, building dwellings or public buildings of an appropriate size and shape, or trading for raw materials.

Our knowledge of early measuring methods comes from many sources. Some measuring devices, including early measuring standards, are still preserved in museums where they can be examined. Some buildings, such as the Egyptian pyramids, still exist and these can be measured directly. Another method is to compare the dimensions of old buildings with the writings of contemporary writers. For example, a fairly accurate idea of the size of the ancient Greek foot was obtained by measuring parts of the Greek Parthenon in Athens and comparing these measurements with a description of the Parthenon written by Plutarch (46/120).

Then as now, the measures were arranged according to the quantity that was being measured. Generally they measured length, mass, volume, and time.

Length

Early measuring methods for length were based on the use of human body parts. Lengths and widths of fingers, thumbs, hands, hand spans, cubits, and body spans seem to have been popular choices. For example, early Babylonian and Egyptian records and the Bible indicate that length was first measured with the forearm (cubit ~ 500 mm), hand (width of male hand ~ 100 mm), or finger (one of three main fingers ~ 20 mm).

The cubit was defined in these cultures as the length from the tip of a man's elbow to the end of his extended fingertips, and obviously this varies widely between different men. For modern men, a cubit can be quite close to 500 millimetres, so if a man puts the tips of his two long fingers together and places his forearms horizontally, his elbows will be quite close to 1 metre apart. The cubit was a commonly used measure in building construction.

Mass (sometimes called weight)

Body parts were not much use for measuring mass so various natural articles, that seemed to be reasonably consistent, were chosen to be the standards. Stones, grains of wheat or other small grains were a common choice. As examples, the word stones (of 6.350 kilograms) are still used to talk about body mass in the UK, and the carob seed became the basis of a measure called a carat (of 200 milligrams exactly) that is still used as a measure for gemstones. Uniform carob seeds must be hard to obtain as the carat has been defined as 200 milligrams for a long time.

The Babylonian people made important improvements following the invention of the balance. Instead of just putting an unknown mass on one scale pan and then placing enough grains in the other pan to balance, they kept some finely shaped and highly polished stones and used these instead of grains (presumably to save them counting); These were possibly the world's first standard masses.

However, the Babylonians used different stones for weighing different commodities (one set of masses for grains, another for gold, and yet another for gems). This is still practiced in modern times with words like Troy ounces and carats still being used instead of the metric units grams and milligrams.

Although the grain was the earliest and most ancient unit of mass, it persists as the smallest unit in the apothecary, avoirdupois, Tower, and troy measuring methods. The grains might be the same but the ounces differ; for example, the Troy pound was divided into 12 Troy ounces while the Avoirdupois pound was divided into 16 ounces.

The early unit was a grain of wheat or barley used to weigh precious metals like silver and gold. Because of this connection with gold and silver, the same mass words were often used as units of both mass and money. You can see this practice in the UK where the word pound is still used as a measure of mass and of money.

Volume (or capacity)

When it was necessary to compare the capacities of containers such as gourds, or clay vessels, they were filled with small plant seeds that were then counted to measure the volume. One interesting measure was the Egyptian 'hon' that had the volume of a cubic palm and corresponded to one mina of water; this corresponds to a modern litre, and can be thought of as measuring 1 hand by 1 hand by 1 hand, where a hand is 100 millimetres.

Time

Time was measured by counting the periods of the sun, moon, and other heavenly bodies. It was assumed that these were consistent in length until better methods showed that days, months, and years all varied in length. In any case they worked well enough to decide when the next market day was to take place or when was the best time to plant next year's crops.

The Egyptians also discovered that, regardless of the season, the shortest shadow cast by any fixed object – such as an obelisk – would always point towards the North. This line pointing North became known as the mid-day line or meridian (from the Latin *medius* = mid + *dies* = day). The meridian line always points in the same direction: toward the North Pole in the northern hemisphere and toward the South Pole in the southern hemisphere. The Egyptians also knew how to find the longest day (at the summer solstice) and the shortest day (at the winter solstice). These points and other points through the year were invaluable in predicting the seasons.

Variations

After archaeologists studied the evidence from all available sources, they decided that there had been no consistent lengths, masses, volumes, or times over any long period of Egyptian history. They found that all the measures changed more or less gradually as time passed. These changes were quite complex because there were many modifying influences.

Similarly, there had been common names like a cubit or a foot in several other nations but these varied in length throughout history and they varied from country to country. The earliest known units used to measure length by ancient peoples are the Egyptian cubit, the Indus Valley units of length, and the Mesopotamian cubit.

Archaeologists now talk about the different measuring methods according to where they come from rather than looking for non-existent consistencies. The common names for groups of measurements that existed before the International System of Units (SI), the modern metric system, are: Babylonian measures, Egyptian measures, Greek measures of the Ptolemaic age, Olympic measures of Greece, Roman measures, British measures, Chinese measures, Inca measures, and many others.

None of these old measures was ever fully organised into a coherent systems of measurement so it is inaccurate to refer to any of them as a 'system' of measurement. The metric system is the only system that has ever existed.

One interesting problem for traders was in the way different people chose to divide their measures into small amounts. Many chose halves, quarters, eighths, sixteenths and so on; others chose thirds and two thirds; some chose twelfths and twentieths; and a fewer number chose to use decimal divisions. People near the centre of trade routes, such as the Babylonians, had the problem of converting between all these different measures and making sense of them all.

People from their West, such as the Egyptians, Greeks and Romans divided their measures into halves, quarters, twelfths, and twentieths, while people from their East, such as China and India, were more inclined at that time to use decimal numbers.

Eventually the Babylonians developed the idea of using a numbering system based on the number 60 – a sexagesimal method of numbering. From there on the conversions were relatively easier because the calculations to go from East traders to West traders used the common denominator of 60. To make this even easier the Babylonians also developed a mass and money method where there were 60 shekels in a mina and 60 minas in a talent. We can also trace the division of the circle into 360 degrees and the day into hours, minutes, and seconds back to the Babylonians use of sexagesimal numbers.

Biblical measures

The need for honest measurements goes back to prehistoric times and there is a lot of uncertainty about its early history. However historical records have shown that all nations throughout time have found the necessity for legislative control in weights and measures. Many of these have been quoted in the Christian Bible.

Of course, the Bible is not the only reference to early metrology but it does highlight the fact that there has been a need for some sort of control relative to weights and measures for thousands of years. It follows that if there was a need for some sort of control thousands of years ago when life was supposed to be simple, then it is hard to see that today's measurement legislation is not absolutely necessary in our more complex society.

Most of us have access to the words used for ancient measures as these are used in the Bible. Even though we know stories such as Noah measuring his ark in cubits, few of us have any idea how the people of those ancient times measured.

The tables below give approximate amounts and distances, but Bible measuring words changed their value from time to time and even from book to book within the Bible. Like all other ancient measures, they varied through time in complex ways because of many different modifying influences. The reason that I am using Bible measures is because the words (although not their values) are familiar to many people. You will see that some of the values are actually decimals where one measure is 10 times another.

The examples below show some biblical length measures and they are a clear demonstration that people appreciated that there was a need for standards of weights and measures for fair and just trading thousands of years ago.

Biblical length	**Modern approximation**
a day's journey	30 kilometres
some distance (a little way)	7 or 8 kilometres
mile (Roman)	1500 metres
a sabbath day's journey (2000 cubits)	1000 metres
stadion	200 metres
rod (or reed)	3 metres or 3000 millimetres
pace	750 millimetres
cubit	500 millimetres

span	250 millimetres
handbreadth	100 millimetres for men 80 millimetres for women
finger width	20 millimetres

Biblical mass	Modern approximation
talent (60 minas)	30 kilograms
mina (50 shekels)	600 grams
shekel (2 bekas)	10 grams
beka (10 gerahs)	5 grams
gerah	0.5 gram or 500 milligrams

Biblical volume measures

Capacity	Biblical measure	Modern approximation	Visualise as
Dry Measure	cor or homer (10 ephahs)	200 litres	Petrol drum
	lethek (5 ephahs)	100 litres	Refrigerator
	ephah (10 omers)	20 litres	Jerry can
	seah (1/3 ephah)	7 litres	Small plastic bucket
	omer (1/10 ephah)	2 litres	Large kitchen jug
	cab (1/18 ephah)	1 litre	Small kitchen jug
Liquid Measure	bath (1 ephah)	20 litres	Large flower pot
	hin (1/6 bath)	3 litres	Milk jug
	log (1/72 bath)	300 millilitres	Kitchen glass

Ancient measurers

The fact that measures varied from time to time and from place to place was not a big impediment to ancient measurers. When people didn't travel much, this problem had less importance. As now, the really important issue was that the measuring words meant the same thing to everyone involved in a transaction or on a building site. This worked as long as the traders understood what the measurement words meant – exactly enough for their particular purpose. However, if the same people went to another town or another building site, all of the measuring words might now have quite different meanings.

If the measuring on a particular job is always done by one person, it doesn't make much difference how accurate measuring sticks are, or even how long they are, as long as you use the same stick each time. However, as soon as a job is assembled from a number of articles that are made then stored, to be assembled by some one else later, standard measures are required; that is, the measurements must mean the same thing to everyone.

Builders of the pyramids appear to have used a cubit to design and measure components for their buildings, based on the distance from the elbow to the tip of the longest finger. A cubit is very useful as it is readily available, convenient, and can't be mislaid, but it is not a positively fixed dimension or a standard. It seems that pyramid builders needed to have a standard cubit as so many people were working on different parts of the same construction, so they created a *Royal cubit* and they had the good sense to make it 7 palms (or 700 millimetres) long, so it wouldn't be confused with the common cubit when it was used in constructing buildings or for surveying. Note that this is not the only Royal cubit. There was a very old Royal cubit, about 520 millimetres long, made from black marble and divided into 7 hands that were further sub-divided into four digits, and then into fractional parts. The smallest division was just a little more than a millimetre.

Although the cubit is no longer used as a unit of measurement, it is still useful to get an approximate length measurement without the need of a ruler or a measuring tape. For many men, it is close to a convenient 500 millimetres (with your longest fingers placed tip to tip your elbows are quite close to a metre apart).

Over long periods of time, the lengths, masses, and measuring containers drifted from place to place. Many words for measuring methods travelled long distances, but often they did not take their definitions with them. This was particularly true for the Roman empire where the uncia, meaning a twelfth, became an ounce in Troy ounces in France, a 16^{th} of a pound in Avoirdupois ounces in the UK, and an inch which was a twelfth of a foot in the UK.

Another example occurs because the Roman soldiers did a lot of marching. As they marched, they kept track of the distance they travelled by counting in lots of a thousand paces – a mille in ancient Roman Latin. A Roman pace was the distance covered from the time one foot touched the ground until that same foot touched the ground again, so a thousand paces was quite close to 1500 metres or 1.5 kilometres. In England, they borrowed the word, mille, and changed the word to 'mile'; it had many definitions over the years. The definition of the current 'metric mile' is exactly 1.609 344 metres.

Then, as now, some people were prepared to use measuring confusion to gain commercial advantages by cheating. For this reason, the early books of the Christian Bible treat measurement almost as a running theme. Here are some examples about measurements taken from the King James Version of the Bible:

Deuteronomy 25:13-14

Thou shalt not have in thy bag divers weights, a great and a small. Thou shalt not have in thine house divers measures, a great and a small. Diverse weights and diverse measures, both of them alike are an abomination to the Lord.

Micah 6:11

Shall I count them pure with the wicked balances, and with the bag of deceitful weights.

Exodus 16:36

Now an homer is the tenth part of an ephah. (This is one of the earliest mentions of decimal divisions for measuring units.)

Leviticus 19:35-36

Ye shall do no unrighteousness in judgment, in meteyard, in weight, or in measure. Just balances, just weights, a just ephah, and a just hin, shall ye have.

Isaiah 5:10

Yea, ten acres of vineyard shall yield one bath, and the seed of an homer shall yield an ephah.

Ezekiel 45

Ye shall have just balances, and a just ephah, and a just bath.

The ephah and the bath shall be of one measure, that the bath may contain the tenth part of an homer, and the ephah the tenth part of an homer: the measure thereof shall be after the homer. (Here's another decimal division but with two names this time – bath for wet goods and ephah for dry goods.)

Amos 8:5

Saying, When will the new moon be gone, that we may sell corn? And the sabbath, that we may set forth wheat, making the ephah small, and the shekel great, and falsifying the balances by deceit?

Note: it is curious that the *homer*, at about 200 litres, is nearly the same size as the standard 200 litre petrol and oil drum designed in Germany in the 1930s. The *bath*, at one tenth of this amount, is equivalent to the small square-shaped fuel carrier that became known in many English-speaking countries as the '*jerry-can*' from its German origins. For most of the 20th century, the 200 litre drum was known as a *44 gallon drum* in the UK and its colonies, and as the *55 gallon drum* in the USA because of their gallons of different sizes. A *hin* was about 4 litres and a shekel was about 12 grams.

4500 BCE

Alexander Thom, in *Megalithic Sites in Britain*, claims to have arrived at close estimations of standard lengths used in the construction of many prehistoric sites in Britain. He examined and carefully measured megalithic (big stone) sites in the UK and Europe. Thom believed that the original builders had been quite competent surveyors and builders who could build within a tolerance of a few millimetres. Thom's analysis of 300 sites led him to believe that there were standard lengths that he called a megalithic yard and a megalithic rod. He estimated their lengths as:

1 megalithic yard in the UK was about 2.720 British Feet (829 millimetres) and
1 megalithic rod was about 2.5 megalithic yard or 6.8 British Feet
(2 073 millimetres).

It is unlikely that the word, yard, was used at this time but other words for the same thing might have been used in Europe. These included the French word, verge, and the Spanish word, vara, that might have had similar lengths: 843 millimetres in Burgos and 756 millimetres in Madrid. Later the Spanish word, vara, was transported to America where its values were nearer to 838 millimetres in Mexico and Peru, and 847 millimetres in California and Texas.

Alexander Thom also explored the way that the measuring units, that he had renamed as megalithic yards and megalithic rods, might be sub-divided. He formed the view that the megalith builders used a small unit that he named a megalithic inch that was one fortieth of a megalithic yard or one hundredth of a megalithic rod – a curiously decimal sub-division. Thom wrote:

... there existed in Britain in Megalithic times a widespread knowledge of geometry. We find designs drawn with the same conventions set out on the ground and inscribed on rocks and stones ...

Thom believed he could identify from these rock carvings that 40 of the small divisions made one Megalithic Yard, and that 100 of them made a megalithic rod because:

... In both there is the same insistence on integral lengths. The linear unit that we find on the rock designs is 0.816 inch (~ 20 millimetres) or exactly one-fortieth of the Megalithic yard used in ground plans. The designer undoubtedly used a set of beam compasses with the distance between the inscribing points advancing by units or half units. This explains the preoccupation with integral lengths and the necessity of using triangles with sides of integral length satisfying the Pythagorean theorem.

3400 BCE

In Egyptian writing (called hieroglyphics) a special symbol for the number 10 was used. This was another early use of decimal numbers.

3100 to 2181 BCE

Construction of the pyramids began during the period in Egypt called the *Old Kingdom*. Inscribed weights from that time suggest that there was a mass unit of 27 grams and another of half this mass at about 13 grams. These mass measures were called deben.

The standard measure for length in Egypt, based on surviving cubit rods, seems to be the cubit of about 500 millimetres long. Larger measures were based on cubits. For example a very large measure, called a *river measure*, seems to correspond to about 20 000 cubits (~10 kilometres).

Measuring area at this time seemed to be based on decimal divisions. From Old Kingdom written sources the main area measures were:

- the tA (called a land-measure) = 10 x 10 cubits (about 25 square metres),
- the xA (called a thousand) = 10 x 100 cubits (about 250 square metres), and
- the setjat (called a xA-tA) = 100 x 100 cubits (about 2500 square metres).

For measuring volume or capacity, Egyptians used three main measures:

- the hin (called a jar),
- the heqat (called a barrel), and
- the khar (called a sack).

The relationship between these was: 1 khar = 10 heqat and 1 heqat = 10 hin. Old inscribed jars with hin measurements show that 1 hin is about 0.5 litres so 1 heqat would be about 5 litres, and 1 khar about 50 litres.

3000 BCE

In very early times the people of ancient India are thought to have used length measures such as the dhanus (or bow suggesting a length based on how far you could shoot an arrow); the krosa (or cow-call suggesting a distance from which you could hear a cow); and the jojana (or stage suggesting a distance of how far you would walk before taking a rest break).

The peoples of Egypt, Mesopotamia, the Indus Valley, and in Iran devised the earliest known uniform weights and measures at about this time. Many different cubits of different lengths were used. In addition, the cubit, the length from your elbow to the tip of the middle finger, was divided in different ways. A common method was to say that the span of your hand (from the tip of your thumb to the tip of your outstretched little finger) was half a cubit, that the palm or width of your hand was one sixth of a cubit, and that the width of your middle finger was one twenty-fourth of a cubit. Another method was to divide the cubit into 7 hands, then into four digits (fingers), and then to divide the finger sub-divisions into fractional parts.

Some historians suggest that the Babylonians had related the measures for length, volume, and mass to each other. The basis of all these co-ordinated measures was a cube with an edge one foot long. The cube, when filled with water, formed a volume of one cubic foot. The water to fill the cube gave a unit of mass. There is some evidence for this idea because the required mass of about 30 kilograms (called a talent) has been found physically and referred to in historical literature. However, the volume measure is not so easy to find; the Biblical bath or ephah at about 20 litres is too small.

2700 BCE

Babylonian astronomers had named the constellations and were able to use the angles between constellations to predict the approximate start of the seasons.

2600 BCE

The most astounding of the ancient methods of measuring was the one that appeared in the Indus Valley. The Indus Valley people achieved great accuracy in measuring length, mass, volume, and time. Their measurements were extremely precise since their smallest length division, which is marked on an ivory scale found in Lothal, was approximately 1.704 mm, the smallest division ever recorded on a scale of the Bronze Age.

Engineers and traders from Harappa in the Indus Valley (now in the Sindh province of Pakistan) used a combined binary and decimal division of measurement. This was based around the number series: 0.05, 0.1, 0.2, 0.5, 1, 2, 5, 10, 20, 50, 100, 200, and 500. For example, the Harappa masses for weighing were shaped as hexahedrons and were based on the recurrence of multiples of the three value number series: 1, 2, 5 ... This can be made larger using 10, 20, 50 or smaller using 0.1, 0.2, 0.5. In this series, 1 is half of 2 and 5 is half of the starting number of the next group of three, 10, which in turn can be divided by 2 in a binary way or by 5 or 10 in a decimal way. The series could then be continued upwards or downwards as required: 0.005, 0.01, 0.02, 0.05, 0.1, 0.2, 0.5, 1, 2, 5, 10, 20, 50, 100, 200, and 500, 1000, 2000, 5000, ...

Many nations now use this method for their decimal currencies. Australia has coins of 5, 10, 20, and 50 cents, 1 and 2 dollars, and then notes of 5, 10 20, 50, and 100 dollars.

It is interesting that the Harappan small unit of mass was about 30 grams and this value persisted as the Roman *uncia* (meaning one twelfth of a Roman *pondus*). Later it became the Italian *onza*; next it was the European and Ethiopian *Maria Theresa ounce* (a bit more than 28 grams); and then as the current English *avoirdupois ounce* with its French name. All of these are now generally included (and legally defined) either as the international avoirdupois ounce of exactly 28.349 523 grams or the international troy ounce of exactly 31.103 476 8 grams.

Lothal, in the modern state of Gujarat, was one of the most prominent cities of the ancient Indus valley civilization and is one of India's most important archaeological sites. The Archaeological Survey of India (ASI) excavated the Lothal site between 1955 and 1960. Here are some more samples from that site, to show the great accuracy in measuring angle, length, mass, and time achieved by the people of the Indus Valley.

S. R. Rao in *Lothal*, Archaeological Survey of India (1985) writes:

> *A thick ring-like shell object found with four slits each in two margins served as a compass to measure angles on plane surfaces or in the horizon in multiples of 40 degrees, up to 360 degrees. Such shell instruments were probably invented to measure 8– 12 whole sections of the horizon and sky, explaining the slits on the lower and upper margins. Archaeologists consider this as evidence that the Lothal experts had achieved something 2,000 years before the Greeks: an 8– 12 fold division of horizon and sky, as well as an instrument for measuring angles and perhaps the position of stars, and for navigation.*

S. R. Rao also writes about measuring lengths in Lothal that he regarded as the finest ever recorded on a Bronze Age measuring scale.

> *An ivory scale from Lothal has the smallest-known decimal divisions in Indus civilization. The scale is 6 millimetres thick, 15 mm broad and the available length is 128 mm, but only 27 graduations are visible over 46 mm, the distance between graduation lines being 1.70 mm.*

When writing about the measurement of mass in Lothal, S. R. Rao writes:

> *The Lothal craftsmen took care to ensure durability and accuracy of stone weights (masses) by blunting edges before polishing.*

Note that the people of Lothal were using decimal measuring methods more than 4 500 years ago.

2500 BCE

The great pyramid of Gizeh was built in Egypt. This pyramid was built using 440 royal cubits (about 230 metres) along each side of the base.

The Harappan people, who flourished in the Punjab between 2500 BCE and 1700 BCE, seem to have developed methods that used uniform weights and measures. These were based on decimal numbers with half values in between. The main series, that went 0.05, 0.1, 0.2, 0.5, 1, 2, 5, 10, 20, 50, 100, 200, and 500, looks a lot like the currencies of many modern nations, such as Australia. When some Harappan scales for measuring length were discovered during excavations they surprised the archaeologists with the accuracy and the precision of their markings. For example, one scale had marks accurately placed 9.322 millimetres apart; 100 of these divisions added to a length of 932.2 millimetres or just a little less than a modern metre. Another example was of a different scale where the small division was 33.5 millimetres; 10 of these would make a rather large '*foot*'; and 3 of the feet would make a length of 1000.5 millimetres, about the length of a long stride and almost the same length as the modern metre.

Archaeological measurements of Harappan building ruins show that the Harappan length measures were accurately used in their building construction.

By about 2500 years ago, Greek sailors applied a deductive reasoning process to estimate the speed of their ships. The ship's speed was determined by counting the number of oar strokes in a time that was measured with a sand glass; the distance travelled over the water was deduced from these figures. Later sailors threw a log tied to a knotted rope into the water then counted the number of knots over a fixed distance. From this practice we acquired the word *knots*, as a measure of speed, and the idea of a *log* book where the speeds were recorded.

2175 BCE

In the ancient city of Gudea, a statue of the governor, Lagash the Prince of Sumer, showed him with some plans and a ruler showing the size of various units. From this a palm was about 100 mm, a cubit was about 500 mm, and so a double cubit was about the length of a modern metre.

Sometime after this, the Babylonians devised a unit of mass based on a hand of about 100 mm. They built a cube (probably from clay) where each side had a length of one hand (100 mm). This was known as a ka and it had a capacity very close to a modern litre. If you filled a ka with water, it became an important unit of mass, called a great mina, which had a mass quite close to the modern kilogram.

At this early stage, there were no standards, so units with the same name could vary in amount from place to place and from time to time. The large cubit, for example, varied from about 400 mm to about 700 mm. No doubt, much of this variation arose from merchants who were somewhat less than honest.

Some of the variation in units also arose from taxation; there was a royal cubit and a common cubit. The king, queen, or Pharaoh simply bought using the royal cubit and subsequently sold using the common cubit – the difference between these two measures was the amount of tax. In Egypt the common cubit was close to 500 mm, while the royal cubit could be as much as 700 mm. Physical evidence still exists of these measures. The ancient Egyptians also had a distance measure, an atour, which was equivalent to 10 000 m or 10 km, a curiously decimal number.

2150 BCE

During the reign of Naram-Sin the Akkadian Empire decided on a single official measuring standard. This was based on a theoretical water container, called the royal gur-cube or šarru kurru, that was 6 metres × 6 metres × 0.5 metre (or 18 cubic metres) from which all other units were derived. The choice of the number 6 now seems strange to us, but the Akkadian Empire at that time used both decimal numbers and other numbers based on the number 6 and 60. Naram-Sin's measurement standard is now regarded as the first rational measurement method in Mesopotamia. Following the demise of the Akkadian Empire the rational measurement standards were not supported and maintained. See **http://en.wikipedia.org/wiki/Ancient_Mesopotamian_units_of_measurement for details.**

2125 to 1700 BCE

During the Middle Kingdom in Egypt there was a recovery from chaos to relative political stability. One Middle Kingdom document refers to *small* and *large* deben, presumably the half deben (~13 grams) and the full deben (~27 grams).

Middle Kingdom wooden rod fragments, found in Lahun and Abydos seem to be standards of length in cubits.

Middle Kingdom accounts suggest that the earlier decimal volume measures were replaced with a halving method of division. Written documents refer to single and double heqat measures and other sources suggest a mixed system of single, double and quadruple heqats.

2000 BCE

Naram-Sin's standard gur-cube or šarru kurru (see 2150 BCE) was again adopted as the measuring standard during the Neo-Sumerian Period. The recording of this law is known as the Nanse Hymn or as the Letter of Nanse. This law reduced multiple measuring methods to a few agreed common standards. Water clocks were also in use in Mesopotamia at this time.

These standards continued to be used by the successors to Sumerian civilization, which included the Babylonians, the Assyrians, and the Persians.

Recent (about 2000 CE) measurement research has focused on using modern statistical techniques to such things as the Statues of Gudea and the 'cubit of Nippu' as well as Sumerian architecture through studying original design drawings and remaining buildings. Some archaeologists maintain that there are several similarities between Sumerian standards and modern metric (SI) standards. See **http://en.wikipedia.org/wiki/Ancient_Mesopotamian_units_of_measurement** for details.

The cubit of Nippur is a copper bar marked with divisions called foot, hand and finger. The cubit of Nippur, at 1103.5 mm, was divided into 4 Sumerian feet (each about 276 mm) = 16 Sumerian hands (each about 69 mm) = 64 Sumerian fingers (each about 17 mm).

Statues of Gudea have been collected from many places in the ancient world. Many of them have plans of palaces or temples with measuring scales attached to them. These figures are about 500 millimetres (1 cubit) high when they show Gudea sitting, and about 1000 millimetres high (2 cubits) when they show Gudea standing.

The Greeks adopted the schoinos as a long unit of length (about 6.3 km). They acquired this from the Egyptians who had adopted it from the Persians.

1850 BCE

A clay tablet from this date, found in Senkerah in Iraq, described a table of linear measures based on the width of a human (presumably male) palm. Other than the palm, it had three cubits: a small cubit of three palms, a medium cubit of four palms, and a large cubit of five palms.

1766 to 1122 BCE

Chinese people used a decimal place number system during the Shang Dynasty. In Chinese characters, ten was written as *ten-blank*, eleven was written as *ten-one* and zero was left as a blank space for a number such as 405 that was written as *four blank five*. An example of how the Chinese used the decimal system may be seen in an inscription from the thirteenth century BCE, where '*547 days*' is written '*Five hundred plus four decades plus seven of days*'.

1550 to 1069 BCE

Another Egyptian Empire arose that we now know as the New Kingdom. At this time there was a change in the masses used for trade with 1 deben (~90 grams) equated to 10 qedet (~9 grams). This is another early decimal division of measuring methods.

During the New Kingdom in Egypt, wooden and stone rods were placed in elite burials, some were inscribed as gifts from the king. Later similar inscribed stone rods were found in temples; perhaps this was where lengths could be checked for trading purposes.

Egyptian sources refer to a measure for land called the *cord measure* that had two sizes, one was about 100 cubits (~50 metres), and another less used one was about 1000 cubits (~500 metres). Surveyors in Egypt were called *cord-stretchers*.

In Egypt, measurements were taken of the Sun's shadow against graduations marked on flat stone surfaces. Some of these still exist in museums. A vertical rod (a gnomon) cast a shadow and the time and the seasons could be measured with reasonable accuracy by closely noting the length and the angle of the shadows.

594 BCE

During the time that Solon (630/560 approx.) was archon, or chief magistrate, of Athens he introduced a coinage system, which consisted of a stater that he divided into 100 drachmas. This was another example of an early decimal currency.

572 BCE

Pythagoras (570/495 approx.) was born in Samos, but because he disagreed with the ruling government, he travelled to Croton, in Calabria in southern Italy, in about 532 BCE. There he set up a school that taught mathematics, including the mathematics of astronomy and music. One of his discoveries that we still use was the proof that:

> *The square of the longest side (the hypotenuse) of any right-angled triangle is equal to the sum of the squares of the other two sides.*

We now know this mathematical rule as Pythagoras' theorem and we usually use it in the form of $a^2 + b^2 = c^2$ where the square of a (a^2) plus the square of b (b^2) is equal to the square of c the hypotenuse (c^2).

The Babylonians probably knew Pythagoras' theorem 1000 years earlier but he was the first to mathematically prove it.

We constantly use many of Pythagoras' ideas. Here are some examples:

- His belief that all naturally occurring relations could be explained and understood using numbers. He showed how numbers could be applied to music.
- Pythagoras and his followers were distressed to find that not all numbers are rational. We now regularly use Pythagoras' irrational numbers such as the square root of 2.
- Pythagoras taught that the Earth was a sphere and not flat. He also knew that the orbit of the Moon was inclined to Earth's equator.

Pythagoras' ideas were essential to the development of measuring methods based on the shape and size of the Earth (see 1792 below).

500 BCE

Thales of Miletus ((620/546 approx.) used shadows to make a projection of the region where he lived and used the lengths to estimate heights and distances.

428 BCEc.

The Greek philosopher, Plato (428/347 approx.) was a student of Socrates (470/399 approx.) and a teacher of Aristotle (384/322 approx.). All three provided foundations for our modern views about mathematics, science, and philosophy many of which are routinely used in metrology.

332 BCE

The city of Alexandria was founded in Egypt.

330 BCE

The thirteen books of Euclid's *Elements of Geometry* were written in Alexandria.

300 BCE

Euclid wrote about the laws of reflection of light.

250 BCE

Archimedes of Syracuse (c 287/c 212) wrote that the Earth revolved around the Sun.

235 BCE

After Eratosthenes of Cyrene (276/194) became director of the library at Alexandria, he gave a remarkably accurate estimate of the Earth's circumference. Eratosthenes wrote a description of the known world in which he calculated the circumference of the Earth to be about 250 000 stadion. Eratosthenes measured the circumference of the Earth using basically the same idea as the French when they defined the length of the metre by measuring the Earth in the 1790s.

Eratosthenes measured the Earth using the distance from Alexandria to Syene (now Aswan on the Nile) in Egypt. He noticed that on the day of the summer solstice, sunlight went straight down the shaft of a well in Syene, so the sun must be directly overhead at Syene. He realised that at the same moment the sun was not overhead in Alexandria, to the north of Syene, because the earth's surface is curved. He went to Alexandria and measured the shadow of an obelisk (a tall stone pillar) in the grounds of the Alexandria library. Using the height of the obelisk and the length of its shadow, he calculated the angle of the Sun at the summer solstice as 1/50 of a circle in Alexandria.

Previously, Eratosthenes also developed a 16 point wind rose that was the first to use the word *degree* so he understood how to measure and to calculate using angles and he knew that there are 360^{o} in a circle. From the sun's shadow, he worked out that Alexandria and Syene were 7.2^{o} apart from each other, on the circumference of the world. He knew that a camel travelled about 100 stadia a day (stadion = approx. 200 metres), and that it took 50 days to go from Syene to Alexandria. So the distance was 5000 stadia. Finally, Eratosthenes multiplied the 5000 up to the full circumference of the world, instead of just Syene to Alexandria: 5000 x 360/7.2. The answer is 250 000 stadia.

Eratosthenes' calculation was not quite right. It was a little too high because Syene is not quite due south of Alexandria, and camels' paces and therefore their speeds are not always the same. Modern values for the Earth's circumference are 40 008 kilometres for the polar circumference and 40 076 kilometres for the equatorial circumference.

221 BCE

Emperor Shi Huang Ti attempted a major measuring reform in China as part of a program to unify the nation. Shih Huang Ti set standards for Chinese weights and measures.

200 BCE

The Indian mathematician Bakhshali used zero in a textbook before 200 BCE. The word 'zero' in English derives from the Indian Sanskrit *sunya* that means empty or blank. This was translated as zifr by Arab writers, then as the Latin zephirum, and finally into English as either *zero* or *cipher*.

129 BCE

The Greek astronomer, geographer, and mathematician Hipparchus (Ἵππαρχος c 190 /c 120) used projections to show heights (sterographs) and perspective (orthographs). He also completed his star catalogue with about 850 stars catalogued by their apparent brightness and their celestial latitude and longitude.

100 BCE

Greece

The width of a forefinger (~ 20 mm) was a common small length measure. A Greek foot was regarded as 16 finger-widths (16 fingers = one foot) that would make each Greek foot 320 millimetres long; this is too long for most people and was probably too long for the Greek people of that time.

Rome

The Romans divided the foot into 12 unciae. Uncia means 'a twelfth part' and assuming the average Roman foot is about the same as ours, about 275 mm, then the original uncia must have been about 23 mm.

As the Romans were a military society, they measured long distances in lots of 1000 double steps, as in left-right-left. This gave them one of the first decimal measures. In modern military terms with a pace of 750 millimetres, two paces is 1500 millimetres and 1000 paces is 1500 metres or 1.5 kilometres.

46 BCE

Roman calendar

Julius Caesar (100 BCE/44 BCE) introduced a new calendar with three years of 365 days followed by a leap year of 366 days. To adjust for the seasons this meant that the year 46 BCE had to have 445 days; this made it the longest year ever.

However, the Roman calendar was fundamentally flawed. It provided for a year that was exactly 365¼ days long when the real year was 365.2425 days long. This meant that the beginning of the year on the calends of Mars gradually moved forward until the seasons no longer matched the dates.

Roman length

Julius Caesar, about the time he reformed the calendar, also approved the method for measuring long distances using 1 000 paces where each pace consisted of two steps. In Latin 1 000 paces is '*mille passus*' and much later, in English, this was shortened from '*mille passus*' to *'mille'*, meaning 1000, and eventually this was shortened to 'mile'.

The Roman mile consisted of 1000 paces, where the 'pace' or double-step was defined as 5 Roman feet so the Roman mile was 5000 Roman feet. The Roman mile of 5000 feet (about 1500 metres) was introduced into England during the occupation of England.

Many European countries also retained a mile of about 5000 Roman feet (however big the local 'feet' were), but in England, the mile was redefined as 5280 feet in an attempt to coordinate the foot and mile with other local measures such as the rod and the furlong.

The Romans spent so much time marching across various countries that they recorded the distances in 'mille passus', each mille comprising a thousand footsteps. They used permanent stones to mark the distance between towns and villages. In addition, each Roman road had occasional small obelisk statues placed to indicate the distance from Rome because, under the Roman Empire, Rome was the centre of the known world. It was said that, *All roads lead to Rome*, and so all distances were measured from Rome.

The Romans probably inherited the word, foot, from Egypt via Greece. A Roman architect, Statilius Aper, had a statue of himself made that included a ruler that has been accurately measured as 296 mm. The Roman foot was sometimes divided into 12 unciae (about 24.7 mm) and sometimes divided into 16 digits (about 18.5 mm).

Assuming that 296 millimetres was the length of a Roman foot and that there were five feet to a Roman pace, and one thousand Roman paces to a mille passus, then a Roman '*mille*' would be 1480 (say 1500) metres.

If we estimate the Roman mile at about 1 500 m, each soldier would have single paces of about 750 mm. They simply selected a pace length that was a little stretched yet comfortable for their smallest soldiers and the taller soldiers kept in step using smaller paces; modern armies still use a standard pace of 750 mm.

Every country that was influenced by Rome 2000 years ago had units with the names 'inch', 'foot' and 'mile, or local languages equivalents. All countries that were part of the Roman Empire had 'inch', 'foot' and 'mile' units but the lengths of these varied widely even within the same country. Countries further away from Roman influence such as China and Japan used other non-Roman units.

It's interesting that people who want to 'go back to miles' really want to use an old Roman decimal system. The metric system currently uses 'milli' to mean one thousandth.

Roman mass

For measuring mass the Romans used scales called 'Libra Pondo'. The word pound is derived from the second part of Libra Pondo and the abbreviation for pound (lb.) is derived from the first part of Libra Pondo. In Latin Libra meant scales and pondo referred to the weights that were placed on the pan of the scales. The Romans shortened Libra Pondo to libra.

The Roman libra of about 500 g was divided as follows:

1 libra = 12 unciae = 48 sicilici = 96 drachmae = 288 scripula = 576 oboli = 1728 siliquae

Pounds, ounces, and hundredweights were other Roman measures of mass. The word ounce is derived from the word for a twelfth – uncia. It is interesting that some people still use a form of uncia as the word inch – and it still means one twelfth. In Rome, there were 12 ounces (unciae) in a pound. This survived into modern times as the 12 ounces in a Troy pound and 12 inches in a Roman foot.

The Romans tried other decimal units. An *as* (from where we got the word ace) was 100th part of a roman talent and a hundredweight, also a talent, meant a 100 libra pondus.

Commercial goods were originally traded simply by number or volume. When weighing of goods began, new units of mass were developed, but these were naturally based on the previously used volume based methods.

The diverse magnitudes of units having the same name, which still appears today in dry and liquid measures in the USA, could have arisen from the nature of the various commodities traded. The larger avoirdupois pound for goods of commerce might have been based on the volume of waterm, that has a higher bulk density than grain.

There is some conjecture that as the two methods developed, one was based on a cubic foot of grain (28.3 litres or 22.4 kilograms), while the other was based on a cubic foot of (the denser) water (28.3 litres or 28.3 kilograms). To support this idea, the difference between the theoretical ratio (1.265) and the historical ratio (1.215) is not too far away, and some historical measuring talents have been found that are approximately equal to the mass of one cubic foot of water (28.3 kilograms).

All the countries of western Europe used roughly similar 'pounds'. In some countries they were divided into 12 ounces and in other countries they were divided into 16 ounces; 12 ounce pounds were common in Italy and southern France, but in Spain and northern Europe 16 ounce pounds were more usual. The name of the 'pound' in Europe usually traces back to one or other part of the Latin 'libra pondo'. Libra is used for 'pound' in

Italy, Spain, and Portugal and in France it is called the livre. Variations of the Latin word 'pondo' are the origin of the English pound, Dutch pond, Danish pund, German pfund, and Russian funt.

In some English speaking nations there are still two different 'pounds' being used – the avoirdupois pound and the Troy pound. The avoirdupois pound is divided into 16 avoirdupois ounces and the Troy pound is divided into 12 Troy ounces. An avoirdupois pound (of 453.592 37 grams) is exactly 175/144 troy pounds. The word avoirdupois comes from the French phrase '*avoir du poids*', which literally means '*to have weight*' and it refers to goods that are sold by weight rather than by volume or by the piece. The troy pound is named after the French market town of Troyes and one Troy pound (of 373.242 grams) is 144/175 of an avoirdupois pound.

Roman angles

The instrument used for setting out right angles for many thousands of years was the *groma* that had been invented and used by the Egyptians in constructing their pyramids. A groma consisted of 4 stones hanging by cords from two sticks joined at right angles. Measurements were made by lining up two of the strings and the point of the construction that was to be set.

The groma worked well on fairly flat construction sites so it was widely used for road construction. A carving on a tomb near Turin dating from the first century CE, shows a groma on the tomb of Lucius Aebutius Faustus, who was described as an *agrimeter*, literally an earth measurer.

55 BCE and 54 BCE

Julius Caesar visited England but chose not to remain there as an occupying force.

25 BCE

A Roman book on architecture describes a device for measuring distances that worked by counting the revolutions of a wheel with a known diameter. These days this would be called an odometer, or a distance-measuring wheel (or more humorously a *metre meter*).

9 CE (Common Era)

Emperor Wang-Mang standardised the measurements of China. These became known as '*the good measures of Wang-Mang*'. However, with the decline of central authority over the centuries, regional measures gradually underwent growing differentiation between the regions and also increased in size – with the (capacity) measure of grain increasing most markedly. By the Ming dynasty, the basic measure of length, the chi or foot, was 400 millimetres longer than under Wang-Mang; the standard unit of mass doubled and the grain measure of capacity quadrupled!

40

Heron of Alexandria (10/70 approx.) described an instrument that he called a dioptra that possibly dated from about 150 BCE. Dioptra comes from the Greek word that means ‘to see through’. A dioptra was used to accurately measure angles and it was the forerunner of the modern theodolite.

43

The Roman conquest of England by Aulus Plautius introduced the Roman 1000 paces as the measure for long marching distances. The Latin term '*mille passus*' for 1000 paces was soon shortened, firstly to '*mille*', and then to '*mile*' in English.

As a Roman double pace was assessed as about 5 English feet, the English mile was considered to be about 5000 English feet. Later, it was stretched to 5280 feet to accommodate exactly 8 furlongs, a popular English measure of the time that derived its name from the length of a furrowed ploughed with the assistance of oxen.

By coincidence, a furlong is roughly the same length as the various Greek and Roman stadions that had been inherited from even more ancient times. It seems to have been the optimal length for the traditional ox-drawn plough before the oxen need to rest.

79

When the Mount Vesuvius volcano erupted burying Pompeii, it preserved many parts of the town and its artefacts. Among these were measuring instruments of the times such as the groma for measuring angles. The Pompeii groma were made with iron main supports with four bronze plumb bobs.

90

Ptolemy (90/168 approx.) was born in Egypt and given the name Claudius Ptolemaeus (Κλαύδιος Πτολεμαίος) that identified him as a Roman citizen, with Greek family connections, who lived in Alexandria in Roman Egypt. He became a mathematician, astronomer, and geographer who is known for two great scientific works: the *Mathematical Treatise* that later became known as *Almagest*, *The Great Treatise,* a book on the known astronomy of the time, and the *Geography*, a thorough description of all the geographical knowledge of the Greco-Roman world.

Ptolemy drew the first conic projection plane map of the Earth with North at the top. The later use of rhumb lines, whereby a ship could steer in a single direction from point to point on the Earth's surface, built on the convention established by Ptolemy.

Ptolemy also devised the 60 minute and 60 second divisions of the 360 degrees in a circle, which led to the idea of a nautical mile being equal to a minute of angle at the Earth's surface.

In the year 150, Ptolemy drew a map of the world that included China, Sri Lanka, and the Malay Peninsula. He had to make a judgement about the Earth's circumference to draw his maps. Unfortunately for him, Eratosthenes' calculations of the size of the Earth had been lost when the libraries of Egypt were destroyed (they were later discovered in Constantinople), and Ptolemy miscalculated. His estimate was closer to 30 000 kilometres instead of the 40 000 kilometres (approx.) we now know.

250 to 900

During the Classic period of Mayan civilisation there is evidence that a symbol for zero was used in their base-20 number system.

400 to 700

The origin of a base-10 positional number system might be traced back to a positional base-10 number system called in Chinese *Hua Ma*. Coincidentally, when the number of pilgrims travelling between China and India reached its peak, decimal numbers began to be used in India in a manner similar to their use in China.

600

With the demise of the Roman Empire at about this time, there was little measurement progress in Europe for the next 500 years of the 'Dark Ages'.

At about this time, China had successfully standardised units of measurement, the *chi*, the *tsin*, and the *cheng*, throughout its territory.

610

The Koran, written between 610 and 632, contains the line:

> *Woe to those who give short weight! Who when they measure against others take full measure; but when they measure to them or weigh to them, diminish!*
>
> (Koran Sura 83)

629

A Chinese traveller, Hiuen Tsiang (602/664 approx.), described Indian measurements as follows:

> *In point of measurements, there is first of all the yojana; this from the time of the holy kings of old has been regarded as a day's march for an army. The old accounts say it is equal to 40 li; according to common reckoning in India it is 30 li, but in the sacred book (of Buddha) the yojana is only 16 li. In the subdivision of distances a yojana is equal to eight krosas (ken-lu-she): a krosa is divided into 500 bows (dhanus): a bow is divided into four cubits (hastas): a cubit is divided into 24 fingers (angulis): a finger is divided into 7 barley corns (yavas): and so on to a louse (yuka), a nit (liksha), a dust grain, a cow's hair, a sheep's hair, a hare's down, a copper water (a small hole in a copper cup for water administration), and so on for seven divisions, till we come to a small grain of dust (anu): this cannot be divided further without arriving at nothingness, and so it is called the infinitely small (paramanu).*

Some historians regard this attempted organisation of measuring words as a system. It is probably better to regard this simply as an attempt to provide some sort of credibility to these old measuring words, even though they obviously had no standard definitions to provide them with any secure foundation. It is better to think of the metric system as the only measuring system that ever existed, and that all previous collections of measuring words were just that – previous collections of measuring words.

670

Arabic mathematicians in Iraq used a zero digit between nonzero digits, but not after nonzero digits.

732

During the reign of Ethelbert II, who was the king of Kent, the 'acre' was in common use. However, there was no real standard as to what an acre was. The size of an acre varied according to how much land could be ploughed in a day. Acres on rough, hilly, or clay ground were smaller acres than land on easily ploughed flat or sandy land; acres nearer to a market town were smaller than acres further away from the market.

742

Charlemagne (742/814 approx.) became King of the Franks in 771 and, by agreement with the pope, he built the Holy Roman Empire that extended from the Vistula River to the Atlantic, from the Baltic Sea to the Pyrenees mountains, and also included nearly all of Italy and some of the Balkans.

During Charlemagne's lifetime he issued several *Capitulare missorum* documents that were intended to protect the whole population from cheating and corruption. Often these were written especially to protect poor people such as wards and widows. Charlemagne also gave encouragement to commerce; the fairs were protected and weights, measures, and prices were regulated.

789

Karaouiyine University was founded in the city of Fez in Morocco. It is the oldest educational institution in the world and still has a mosque and a library. The university re-established the concept of a decimal point based on its use in India. Probably because of Karaouiyine University, at one time Fez was the largest city on Earth.

The university was founded following a bequest from a remarkable woman, Fatima al-Fihria, who had fled religious persecution in Tunisia. Fatima's generosity is greater than it might appear as, being a woman, she couldn't attend her own university. However men from all over North Africa, the Middle East and Europe did attend, and this gathering of students had a major impact on mediaeval Europe, as the male students included both

Muslims and Christians. The university had an effect on the decimal metric system in Europe after Gerbert d'Aurillac attended there in about 965 (see 965 below).

800

In Baghdad, a school of science was founded.

807

Charlemagne introduced uniform length and weight measures in his empire. Like many kings both before and after him he was aiming to reduce the number of existing measurements, to simplify measurement and reduce cheating. Charlemagne tried to standardise measurement through much of Europe by sending model weights and measures to all parts of his empire. Unfortunately these failed to overcome centuries of traders, kings, princes, queens, bishops, cardinals and popes making their own measures that suited their individual commercial practices and aspirations.

830

The Arab mathematician Abu Ja'far Muhammad ibn Musa al-Khwarizmi (790/840 approx.) described the use of 0 (zero) in his book, *Hisab al-jabr w'al-muqabala*. From that name we get the name 'algebra' for that part of mathematics where symbols are used to develop general mathematical principles. Algebra was one of the two operations he used to solve quadratic equations. From the Latin form of al Khwarizmi we get the word algorithm for a logical step-by-step procedure. Another of Al-Khwarizimi's books is called '*Concerning the Hindu Art of Reckoning*' and this is largely a translation of the arithmetic and algebra works of the Indian mathematician *Brahmagupta*, added to several ancient Greek mathematical manuscripts.

Our modern numbers are sometimes called Indian/Arabic numbers because Arab scholars learned of the numbers 1, 2, 3, 4, 5, 6, 7, 8, 9 and 0 from the Indian people through the work of al-Khwarizmi. Latin translations of al-Khwarizmi's works spread to Europe after Adelard of Bath translated them in the early 12th century (see 1080 below). European people soon saw the value of these decimal calculating methods.

In addition to the numbers 1, 2, 3, 4, 5, 6, 7, 8, 9 and 0 al-Khwarizmi's works also introduced these concepts to a European audience: algebra, astrolabes, astronomical tables, better clocks, calculus of two errors (a precursor to differential calculus), higher-order equations, map theory, trigonometry tables, and volumetric analysis.

Astrolabes were used by astronomers, navigators, land surveyors, and for timekeeping both on a daily basis and for calendars. You can predict the positions of the Sun, Moon, planets and stars using an astrolabe. The Hindu Arabic numbers 1, 2, 3, 4, 5, 6, 7, 8, 9 and 0 form the basis of the decimal system that we all use today.

874

Arabic mathematicians used a base 10 positional numeral system, with a zero between numbers and also after nonzero numbers.

900 about

The rod, also called a pole or a perch, was a traditional Saxon land measure that had originally been defined as ... *the total length of the left feet of the first sixteen men to leave church on Sunday morning*.

960

Around the middle of the 10th century the Saxon King Edgar the Peaceful kept *The Yardstick* at Winchester as the official standard of measurement for the southern Saxon lands. He issued a decree that all measures must agree with standards kept in Winchester. Little is known about this standard of measurement other than its existence in historical records.

965 about

One of the people who attended Karaouiyine University (see 789 above) was Gerbert d'Aurillac (946/1003 approx.) who was a prolific scholar and teacher who, even though he was French, became Pope Silvester II. Due to his connection with the Islamic world, speculation that he had Sephardic-Jewish ancestry, and especially because of his interests in science and intellectual thought, there were many rumors about Pope Silvester II being a sorcerer and in league with the devil.

Gerbert d'Aurillac introduced knowledge of Arabic arithmetic, mathematics and astronomy to Europe, especially to France and Italy, including Arabic numerals and the concept of zero.

976

Robert K. G. Temple in his book, *The Genius of China – 3,000 Years of Science, Discovery and Invention* says that the first evidence of decimal numbers in Europe was published in a Spanish manuscript.

1000 to 1500 about

In medieval Europe, trade guilds set the local laws on weights and measures (largely to suit themselves) on a city-by-city basis. For example, an ell was a measure of length commonly used for buying and selling fabrics. In Europe the length of an ell varied from about 400 millimetres Germany, to about 700 millimetres in The Netherlands, and to about 950 millimetres in Scotland.

1038

Ibn al-Haytham al Hazan, (usually known simply as al Hazan), one of the earliest experimenters and pioneers of optical science, published seven volumes of experiments, mathematics, and explanations of observations that he called '*Optics*'. He wrote that vision was the result of rays of light reaching the eye from external sources. He taught that light rays emanated in straight lines from every point of a luminous object such as the Sun or a star. He also studied reflection by mirrors, refraction by lenses and magnifying glasses. For his studies on refraction, he wrote about the angle at which light is bent when passing from one medium to another. Later, translations of *Optics* into Latin influenced scientists, such as Roger Bacon (1214/1292 approx.), René Descartes (1596/1650), Pierre de Fermat (1601/1665), and Johannes Kepler (1571/1630).

1080

Adelard of Bath (1080/1152 approx.) was born in Bath. He is included in this chronology because he introduced Indian/Arabic decimal numbers into England and into Europe with the even more important addition of the concept of zero in his Latin translation (with commentaries) of al-Khwarizmi's *Hisab al-jabr w'al-muqabala* (see 830 above)..

In many ways it was the introduction to Europe of Indian/Arabic numbers and the use of zero that helped Europe revive after many centuries of dark ages. The use of zero made it possible to calculate without using counters in a checkerboard pattern of squares marked out on a table.

Adelard of Bath developed his ideas when he travelled extensively and studied at Tours and Laon in France, Salerno in Italy, Syracuse in Sicily, Athens in Greece, and Antioch in Syria. When he returned to England he translated many important Arabic and Greek scientific works on astronomy, philosophy and mathematics into Latin. It was Adelard of Bath who introduced many of these new ideas to Europe and especially to England. Sometimes we forget how much the proto-science of ancient astronomy has contributed to accuracy in measurement.

His book *Quaestiones Naturales* (Natural Questions), showed how reason and observation could be used to explain natural events. Because of his studies, Louise

Cochrane titled her book, *Adelard of Bath, the First English Scientist* (British Museum Press 1994).

1100

The University of Paris was founded

1101

There is a story that King Henry I of England (reigned 1100/1135) is reported to have introduced a length measure, called a yard, and decreed that a yard is ... *the distance from the tip of the King's nose to the end of his outstretched middle finger*.

Before this, and as early as the middle of the 10th century, it was believed that the Saxon king Edgar the Peaceful kept a *yardstick* at Winchester as the official standard of measurement. It would appear that Henry had lost Edgar's *Yardstick* or, more likely, it had been destroyed.

The story about King Henry is probably based on the Chronicles of William of Malmesbury (1095/1143) who tells how a *false yard* was corrected by referring it to the length of King Henry I's arm. However, William does not say that this was the origin of the yard. The word yard existed in the keeping of the guilds that dealt in cloth before Henry I was born. Whatever the truth of the story about King Henry I, it is probably true that the kingdom needed some sort of standardising laws as several different yards were then in use in England.

The origin of the word *yard* to mean a measure of length is not definitely known. Some believe the origin was the double cubit; others believe that it came from half a French toise (or half a fathom); still others say that it is associated with the word '*gyrd*' (a rod), or with the circumference of a man's waist. Binary numbers, 2, 4, 8, 16, divided the early yard and the parts were known as the half-yard, the span, the finger, and the nail.

In the time of King Henry I, the Chancellor of the Exchequer got his title from the counting checkerboard that he used to count out the king's taxes and expenses. The Exchequer's table was covered with a cloth with embroidered rows and columns and it was large enough (3 metres long and 1.5 metres wide) for calculations to be supervised publicly – and you can be sure that every move was closely watched. When a zero was needed one of the squares on the Exchequer's table was simply left empty. As this was a time when the use of the abacus was increasing in England, it seems likely that Adelard of Bath had an official role at the Exchequer's table of Henry I (see 1107).

1105 to 1114

Adelard of Bath travelled to Salerno, Spain, Italy, Sicily, Greece and probably Toledo, Asia Minor, and North Africa. He is recorded as being in Manistra near Antioch standing on a bridge when a severe earthquake struck there in 1114.

1107

Adelard of Bath wrote a treatise on the use of the *Regule Abaci* (Abacus), a device to help calculating problems in arithmetic. The abacus is sometimes incorrectly called an early hand-held calculator, but it is really a register or accumulator for remembering what has been counted. Adelard recorded the names of the Indian/Arabic numbers as:

> *Igin (1), Andras (2), Ornis (3), Artoes (4), Quinis (5), Caletes (6), Zenis (7), Temerias (8) and Calentes (9).*

The zero (*cifra, circulus, sepos, or theca*) was a little more complex as it had several different names and symbols that were all some sort of circular shape, sometimes with a bar through the middle like the Greek letter theta and sometimes with a dot in the middle like a target. Eventually, however, these were simplified into a simple written circle or oval which was easier to write with a quill pen carved from a feather.

For an intriguing treatment of this, I commend Robert Kaplan's book, *The Nothing That Is: A Natural History of Zero*. Kaplan suggests '*that O arose from the depression left by a circular counter's removal* ' on a sand-covered counting board (precursor of the abacus).

1116 to 1152

During these years Adelard of Bath wrote original works and made important translations from Greek and Arabic into Latin.

He wrote *Quaestiones Naturales* (Natural Questions) that included more than 50 questions on what we would consider today to be scientific matters. Here are some of the questions he tried to answer:

What is the shape of the Earth (he believed it was round)*?*

Why is the sea salty?

Why do some animals see better at night?

How are the Sun and the Moon supported in the air?

What causes tides?

How does the Earth remains stationary in space?

How would a rock fall if dropped into a hole through the Earth (centres of gravity)*?*

How is it that matter is not destroyed when it changes in chemical reactions (conservation of matter)*?*

Why does water experience difficulty flowing out of a bottle-shaped container that has been turned upside down (atmospheric pressure and vacuum)*?*

As an example of his writing, he says of the manners and customs of his own country that:

> *... he has learned that its chief men are violent, its magistrates wine-lovers, its judges mercenary, its patrons fickle, private men sycophants, those who make promises deceitful, friends full of jealousy, and almost all men self-seekers.*

He wrote a book, *De opere astrolapsus*, on the astrolabe (see 830 above) which showed how an astrolabe could be used to:

- calculate the heights of buildings and the depth of pits and wells;
- determine the longitude and latitude of any place (the astrolabe continued to be used for navigation until the 17th Century);
- show the precise positions of the stars and planets in relation to the fixed stars;
- tell the time by day or by night.

He translated *Zij,* the astronomical tables of al-Khwarizmi (see year 830 above). This is now highly regarded, as the original manuscript no longer exists.

He translated the thirteen books of Euclid's *Elements of Geometry* into Latin, from an Arabic translation of the Greek original. Adelard of Bath's translation then became the basis of European mathematics for many hundreds of years.

1150

King David I of Scotland defined the inch as the width of a man's thumb at the base of the nail.

1167

The University of Oxford was founded.

1196 November 20

King Richard I (Richard the Lionheart – reigned 1190/1199) of England proclaimed an '*Assize of Measures*' during which the first documentation of a standardised unit of measurement was made. It read:

> *Throughout the realm there shall be the same yard of the same size and it should be of iron.*

King Richard then had defined standards made in the form of iron rods as '*the iron yard of our Lord the King*' and these were distributed throughout the nation. The expression '*measured by the King's iron rod*' appears frequently in subsequent records, especially in legal records.

Prior to this all English measures were defined in terms of an inch where

> *... it is ordained that 3 grains of barley, dry chosen from the middle of the ear, full and round, make an inch; 12 inches make a foot; 3 feet make an Ulna; and 5 and a half Ulnae make a rod.*

1202

The man who brought Indian/Arabic decimal numbers to Europe was Leonardo Bonacci (1170/1250 approx.) known as Fibonacci, which was a short form of the Latin *Filius Bonacci* (son of Bonacci)).

Fibonacci's father was a merchant who served as a customs officer in Algeria in North Africa. His son went with him, travelled widely in Algeria and later went on business trips to Egypt, Syria, Greece, Sicily and Provence in France. As he travelled he learned the different methods that people used to count and to calculate. Fibonacci had a natural talent for mathematics and he won many of the calculating contests that were popular at that time.

When Fibonacci returned to Pisa he used the knowledge gained on his travels to write *Liber abaci* (*The Book of Calculations*) in which he reintroduced decimal numbers to Europe. The first chapter begins with these words.

> *These are the nine figures of the Indians: 9 8 7 6 5 4 3 2 1. With these nine figures, and with this sign 0 which in Arabic is called zephirum, any number can be written, as will be demonstrated.*

Before Adelard of Bath and Fibonacci, European people were still using the numbers left behind by the Roman Empire. Even in the 21st century some people still use Roman numerals. For example, notices after films and television programs give the year as something like MCMXCVIII (for 1998).

Fibonacci's book became very popular because of the obvious advantages of decimal numbers over Roman numerals. However, it was not a smooth transition. Several attempts were made by church officials to suppress Fibonacci's book because they believed that it was foreign and because it came from Islamic scholarship. His book was extremely important in starting the progress of getting the decimal system universally adopted.

Technically, Fibonacci encouraged the use of one of the most important discoveries of early mathematics – a fully positional notation with a representation for the number zero – we now all learn this in our first few years at school.

Our present use of decimal numbers for all of our counting and calculating is based on two separate discoveries: the Indian/Arabic decimal numbers brought to Europe by Adelard of Bath and Fibonacci and the decimal point from John Napier, Laird of Merchiston, in 1616 (see below). The word, decimal, is derived from the Latin decimus, meaning a tenth.

Our decimal number system is called a base 10 system because it is a positional numeral system using 10 as its base and requiring 10 different numerals, the digits 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, and a comma or a dot (called the decimal marker or the decimal point).

Despite the long history of people using decimal numbers, in 1986 Witold Kula in his book *Measures and Men* felt a need to re-argue the case against using decimal numbers in favour of numbers based on halves (1/2, 1/4, 1/8, 1/16 etc), duodecimals (divided by 12s), vigesimals (divided by 20s), and sexdecimals (divided by 60s).

1209

The University of Cambridge was founded.

1215

A major attempt to standardise English measures was included in the *Magna Carta*. The English King John (reigned 1199/1216), also known as 'Lackland', was forced by his Barons to sign a document called the *Magna Carta*, which among other things had a clause that provided for uniform weights and measures. In part the *Magna Carta* read:

> *There shall be one measure of wine throughout our whole realm, and one measure of ale and one measure of corn--namely, the London quart;--and one width of dyed and resset and hauberk cloths--namely, two ells below the selvage. And with weights, moreover, it shall be as with measures.*

To see a copy of the original Magna Carta go to:

http://www.bl.uk/treasures/magnacarta/magna_main.html

Clearly the Magna Carta was among other things another attempt to standardise measures, particularly of wine and beer, throughout England.

1242

Roger Bacon (1214/1292 approx.) is famous for making accurate predictions without any experiments. For example, he believed that the earth was round and that people could sail all the way around it; this was not done until some of Ferdinand Magellan's crew returned to Spain in 1522.

Roger Bacon carried out experiments on lenses and mirrors and he made his own magnifying glasses. He was the first person to think of a refracting telescope but he didn't make one. In 1242, he invented and wrote exact formulas for making gunpowder, which was in regular military use within 100 years.

1266

King Henry III (reigned 1216/1272) set out a standard based on the weight of grains of wheat:

> *The English penny which is called a sterlyng, round and uncut, ought to weigh 32 grains of wheate taken from the middle of the ear. And the ounce to weigh 20 pennies. And 12 ounces make the London pound, that is to say 20 shillings sterlyng.*

In England, this was yet another attempt to standardise measurement. This law made a clear connection between money and mass, in that 240 pennies (of money) was made equal to one pound (of mass). The same law also provided for eight pounds to be the weight of a gallon of wine. Despite this attempt to standardise measurements, variations and abuses continued long after the law was passed. For example, there were still three different gallons (ale, wine and corn).

1267

Roger Bacon sent a copy of his *Opus Majus* (Latin for *Greater Work*) to Pope Clement IV. In this 840 page book, he writes about:

- ⊇ his explanation of the colours of the rainbow,
- ⊇ his recipe for gunpowder,
- ⊇ his proof that a candle will not burn without air,
- ⊇ several studies of gases including some thoughts on hot air balloons,
- ⊇ his description of a telescope,
- ⊇ his thoughts on ships going without sails, and
- ⊇ his description of the relationship between philosophy and theology that concluded that Holy Scripture is the foundation of all sciences.

1272

Gradually in England, the kings and queens responded to the requirements of the *Magna Carta* (see 1215). However, standards of measurement were not firmly established until later in the 13th century, though variations (and abuses) continued until long after that.

King Edward I of England (reigned 1272/1307), who was known as Longshanks because of his extraordinary height of 1.9 metres, took a step forward in 1272 when he ordered a permanent measuring stick made of iron to serve as a master standard yardstick for the entire kingdom. This master yardstick was called the "iron ulna", after the bone of the forearm, and it was standardized as close to the length of a modern yard (now defined as exactly 914.4 millimetres). King Edward I realized that constancy and permanence were the key to any standard.

He also decreed that the foot measure should be one-third the length of the yard, and the inch one thirty-sixth.

During Edward I's reign the Ulna (or yard) and its sub -and aggregated divisions were defined in terms of barleycorns:

> *It is remembered that the Iron Ulna of our Lord the King contains three feet and no more; and the foot must contain twelve inches, measured by the correct measure of this kind of ulna; that is to say, one thirty-sixth part (of) the said ulna makes one inch, neither more nor less ... It is ordained that three grains of barley, dry and round make an inch, twelve inches make a foot; three feet make an ulna; five and a half ulna makes a perch (rod); and forty perches in length and four perches in breadth make an acre.*

The perch or rod was also used at this time. It had previously been defined as:

> *the total length of the left feet of the first sixteen men to leave church on Sunday morning* (see the year 900).

1297

King Edward I agreed to the Charter of Confirmation. It established the parliament in the UK as a representative body, and it promoted the importance of Magna Carta by declaring all judgments contrary to this document to be null and void. This gave this line from the Magna Carta more relevance as the '*supreme law of the land*':

> *There shall be one measure of wine throughout our whole realm, and one measure of ale and one measure of corn ...*

1299

Catholic church leaders issued an edict that forbade the bankers of Florence from using the '*infidel*' decimal numerals.

1300

Although the Greeks knew that a lodestone could attract iron, Flavio Gioja, an Italian marine pilot, is credited with perfecting the sailor's compass by freely suspending a magnetised needle and enclosing the compass in a box with a glass cover. The compass was soon used in discovering many new lands.

1302

The États Généraux, the General Assembly of France, met using the motto '*One king, one law, one weight, one measure'*. After several sessions it was discovered that the noblemen and the guilds were bribing politicians to vote against reform of weight and measures, because they were profiting greatly from the prevailing measuring confusion.

1303

In England an Assize of Weights and Measures was held and another attempt was made to standardise measures. One of its decrees was:

> *... an English penny, which shall be called sterling, round without clipping, shall weigh 32 grains of wheat dry in the midst of the ear, and twenty pence do make an ounce, and 12 ounces one pound and 8 pounds do make a gallon of wine, and 8 gallons do make a London bushel, which is the eighth part of a quarter.*

From this it is clear that several units with the same name – pound – were to measure mass, weight, money, and capacity or volume. At the time there were several English pounds: the Tower pound was probably the one meant by the Assize, but there were also lighter pounds such as the subtill pound and the foyle pound. Later the troy pound and the avoirdupois pound, both from France, joined all the other pounds in England.

1304

A law was promulgated in England that, for medicines, a pound would weigh the same as 20 shillings of money, or 12 ounces of weight. Other things, which were not medicines, were to be weighed with a pound of 15 ounces. However, in both cases, an ounce was the same weight as 20 pennies.

1324

The inch was re-established in England as the length of three barley grains taken from the centre of an ear by King Edward II (reigned 1307/1327) when he reverted back to the seed concept of the ancients and passed a statute that '*three barleycorns, round and dry make an inch'*. The 'yardstick' of Edward I was no longer legal. This barleycorn definition also redefined the foot, yard, rod, pole, perch, and mile to suit the new, highly variable, inch.

1335

The word clock is associated with bells. If a device for keeping time does not have some sort of a bell, it is technically called a timepiece.

There was a working mechanical clock in Milan in 1335. In *A history of mechanical inventions*, Abbott Payson Usher quotes from *Mesure du Temps* by Berthoud who describes this clock as follows:

> *There is a wonderful clock, because there is a very large clapper which strikes a bell twenty-four times, according to the XXIV hours of the day and night, and thus at the first hour of the night gives one sound, at the second two strokes, at the third three and at the fourth four; and so distinguishes one hour from another, which is of the greatest use to men of every degree.*

The Milan clock is regarded as the first mechanical clock because, although there might have been clocks before then, evidence for them is limited. Several more mechanical clocks were operating in Italy by 1350.

1350

Around 1350, nobles and clergy who had properties on both sides of the channel were introducing measuring methods from France. Using two measuring methods, English and French, soon led to confusion. Edward III, Henry V and Henry VII all tried and failed to simplify exchange between the two methods.

1400

England was another nation using decimal measures in the early fifteenth century – 100 fathoms in a furlong and ten furlongs in a mile. It also had a measure called a 'wand' that in modern terms would be 1007 mm long – only a bit longer than the modern metre. An interesting use of this 1007 mm wand was to make a tun, which was a box 1007 mm long, wide, and high. This was used to store dried grain for one family for a year. Each full moon progress was checked, and if the level had fallen more than a man's hand width (about 100 mm), rationing was required or the tun would not last till next harvest.

1440

The advisers to Henry VI (reigned 1422/1461 and 1470/1471) changed the developing decimal system in England back to non-decimal methods, somewhere around 1440. More complicated measuring methods have, throughout history, often replaced simple measures, usually for commercial, political, or religious reasons.

1450

In a Latin codex, a collection of ancient manuscript texts published in Munich, Theodericus Ruffi used a decimal division of the degree.

1452

Leonardo da Vinci (1452/1519)

Leonardo da Vinci is the usual name given to Leonardo di ser Piero da Vinci and this is usually shortened simply to Leonardo.

Leonardo is widely considered to be one of the greatest painters of all time; he is especially remembered for *The Last Supper* and the *Mona Lisa*.

More importantly for the metric system, Leonardo was an anatomist, architect, botanist, engineer, geologist, inventor, mathematician, musician, painter, scientist, sculptor, and writer who constantly measured so he could invent. His inventions inc luded: helicopters, hydraulic pumps, mortar shells, musical instruments, parachutes, reversible crank mechanisms, and steam cannons.

Leonardo was interested in the measurement of time. He observed pendulums swinging and suggested that they did so with a regular beat for any given length of string, as long as they didn't swing too far from side to side. Leonardo made this observation a century earlier than Galileo Galilei, but neither of them actually built a pendulum based clock.

1466

A chart of Nicolaus Germanus divided the degree into 60 equal divisions that he called miles. His map was based on the incorrect Earth circumference of Ptolemy (about 30 000 km instead of 40 000 km) but it neatly gave him a nautical mile that was, he thought, near enough to the same length as a Roman statute mile. This error became the world standard for at least a hundred years, especially in shipping communities.

1476

Caxton invented the printing press.

1482

Johannes Campanus published his first printed edition of the 13 books of Euclid's

Elements after the invention of the printing press, and probably used Adelard of Bath's translation. This became the chief textbook of the mathematical schools of Europe and continued to be used into the 20th century.

1492

In the year 150 Ptolemy (see 90 above) drew a map of the world that included China, Sri Lanka, and parts of Malaysia. He also estimated the circumference of the world, but at about 30 000 kilometres, he got it wrong – the circumference of the world is quite close to 40 000 kilometres.

The Ptolemy map was the kind of map and scale used by Christopher Columbus. The navigators of Columbus' time did not have any sort of timing device to determine exact longitude. The best 15th century information available to Columbus came from Ptolemy. In 1492 Columbus sailed around an Earth that was at least 33% larger than he was led to believe.

The error by Ptolemy directly resulted in Columbus' declaring that he had reached and was exploring India when he had only got to what we now call America. Since Christopher Columbus' time more accurate measurements of the world's circumference have kept changing until we finally have co ,me to accept 40 005 kilometres as a good average.

Francisco Pellos (1450/1500) published a commercial arithmetic book called *Compendio de lo abaco*, where he used a dot to represent division by 10. He used terms such as: '*numbre desenal*' and '*numbre plus que desenal*' to refer to decimal numbers.

1496

Unscrupulous traders introduced many measuring discrepancies into English market places, so new standards of length were ordered following a parliamentary inquiry.

1497

A fire burned down the king's residence at Sheen (later rebuilt as Richmond Palace). The standard of length (the Iron Ulna) must have been lost because it is thought that King Henry VII (reigned 1485/1509) went back 350 years to obtain his length standard. Some think that he found the wooden yard of Edgar I (the Peaceful), one of the earliest Anglo-Saxon standards. and made a direct copy of it.

This yard of Henry VII, which became known as the *Exchequers Standard* because of where it was stored, is now housed in the Science Museum in London.

King Henry VII tried to make his measurement and weight methods binding on all the people in England.

> *This Yard rule was made at the command of Henry VII, King of England ... to act as an Exchequer standard of length. Copies of the rule were issued to the various boroughs around England to enforce and encourage true measure in trade and commerce. This standard was not a success and was superseded by a more accurate length standard produced during the reign of Queen Elizabeth I around 1588.*
>
> Science Museum, London

It is thought that this new yard (915 mm), with its associated foot one third of its length (305 mm), was an attempt to secure uniformity of the basic length units instead of the diversity of '*foot*' measures that had survived from earlier times in England and Wales.

They included: Greek common foot – 317 mm, Roman foot – 296 mm, Welsh foot – 251 mm, Saxon foot – 335 mm

1507

In his book, *Mercator: the man who mapped the planet* (Phoenix Paperback 2002), Nicholas Crane wrote:

West of the Rhine, in the mountains of Lorraine, the remarkable Martin Waldseemüller launched his cartographic career in 1507 with a book – 'Cosmographiae introductio' – in which he (or his collaborator Matthias Ringmann) suggested that the continent visited by Columbus should be named after Amerigo Vespucci.

It was Italian-born Vespucci who had first suggested that '*the continent visited by Columbus*' (now known as South America) was a landmass previously unknown to Afro-Eurasians.

Nicholas Crane quotes Waldseemüller as follows:

Since another fourth part [of the world] has been discovered by Americus Vesputius, I do not see why anyone should object to its being called after Americus the discoverer, a man of natural wisdom, Land of Americus or America, since both Europe and Asia have derived their names from women.

Crane goes on to say:

'Cosmographiae introductio' was accompanied by a globe on which was marked the continent 'America', and a large map of the world containing the islands and countries recently discovered by the Spaniard Americus Vespucius in the western sea.

1512

A Tractado subtilisimo d'arithmetica y de geometria by Juan de Ortega (1480/1568) referred to '*lo numero decenale*'. It used decimal numbers for commercial arithmetic and for geometry.

1519

Ferdinand Magellan (1480/1521) was a Portuguese maritime explorer who tried to find a way to the Spice Islands of Indonesia by sailing west from Portugal. He had earlier travelled eastward to the Spice Islands, so he became one of the first to sail all the way around the world. Magellan had access to charts, a globe, theodolites, quadrants, compasses, magnetic needles, hourglasses, and timepieces.

Although, within crude limits, speed and compass indications could be used to determine estimated distance and estimated longitude, Magellan was not able to determine his exact longitude because he didn't have an accurate way of telling the time. He could only use an approximate process called dead reckoning. What he needed was a chronometer, but this had not yet been invented.

1528

King James V (reigned 1513/1542) was nominally King of Scotland from 1513 when he was less than a year old, but effectively he did not become king until 1528. For a standard of length the Scots had to rely on James V's pronouncement that:

Tak' the meesure of a sma' maun's nose to his finger-tip. Tak' the same from a reeg'lar maun, and a meikle maun. Combine all and divide by three. Yon is yi'r Yaird.

1530

The French mathematician, Orontius Fineus (1494/1555), discovered the trick of moving the decimal point. When he wanted the square root of 10 he found the square root of 10 000 000 instead, and then moved the decimal marker three places to the left. In a modern notation his calculation would look like this:

$$\textbf{If } \sqrt{10\,000\,000} = 3162 \textbf{ then } \sqrt{10} = 3.162$$

Gerhard de Kremer, also known as Gerardus Mercator (1512/1594) named the continent that was north of America as '*Americae pars Septentrionalis*' that translates as *North America (*see 1507 above).

It is thought that Mercator named the new continent after Spain's most famous navigator, the Italian born Amerigo Vespucci. Nicholas Crane suggests that Mercator might have been influenced by councillors from the Spanish court, which at that time was located in Brussels. Nicholas Crane thinks that several councillors from the Spanish Court might have influenced Mercator when he wrote:

> *Surely, it was these councillors who prompted Mercator to occupy 'North America' with the only historical caption of its size on the map, a caption which read 'Hispania maior capta anno 1530' -'Greater Spain, seized in the year 1530'.*
>
> *Thus, the most modern world map in the Low Countries confirmed that America was not only separate from Asia, but that it had a northern relative who was larger even than Europe, and that both Americas belonged to Spain. With a single nomenclative flourish, Mercator had erected an Imperial barrier to the Indies that ran from pole to pole.*

1533

Peter Apian (1495/1552), a German mathematician and astronomer, published a table of sines with the radius divided decimally in his book of *'Trigonometrical Tables (Natural)*'.

Nicholas Crane in his book, *Mercator: the man who mapped the planet*, reports how Mercator's mathematics tutor, Gemma Frisius, described how to survey any area by triangulation. Crane writes:

> *... Gemma described how to survey an area of any size on the basis of a single ground measurement. All his readers required was a makeshift instrument: a flat piece of wood inscribed with a graduated circle, from the centre of which revolved a pointer -an alidade -fitted with pins, for sights. By holding the 'planimetrum' level and orienting it with a compass so that its north-south line was parallel with magnetic north, the surveyor could rotate the pointer until its sights were aligned with the landmark in question. The bearing was read from the graduated circle. By taking bearings from two landmarks, the position of a third could be fixed. Gemma suggested that the surveyor began by ascending a suitable highpoint, such as the tallest tower in a town, taking a series of bearings in a circle, then adding them to a circle drawn on paper. (He) then described how to repeat the process from a second tower, using the intersecting sight-lines to fix each landmark. Gemma finally pointed out that a third set of bearings would resolve any problems caused by two sight-lines converging in a straight line. Coasts and rivers, he added, could be mapped in the same way.*
>
> *To draw a map to a known scale, continued Gemma, the surveyor needed to create a base-line by measuring the actual distance between two of the centres. He gave Mechelen and Antwerp as an example, and described how to replicate their relative positions at a reduced scale on the map. Distances between other places on the map could be calculated using similar triangles. (In walking from Louvain to Antwerp, Mercator had effectively followed Gemma's instruction that a base-line could be measured 'by walking over this distance'. A measured base-line from Louvain to Antwerp would have been sufficient to embark upon the first mathematical survey of the region.)*

This triangulation technique – invented by Gemma Frisius and then developed by Gerard Mercator – was essentially the same method used by Jean-Baptiste Delambre and Pierre François-André Méchain for their measurement of the meridian between Dunkerque in France and Barcelona in Spain starting in 1792 (see below).

1543

Nicolas Copernicus (1473/1543) published his description of the solar system with the Sun in the centre and the planets revolving around it. He is reputed to have awoken from a stroke-induced coma, looked at his book, and then died peacefully.

1557

King Henry II of France (reigned 1547/1559) issued a weights and measures edict at a time when the predominant issue of the French government was about disputes between Catholics and Protestants.

1560

Giambattista della Porta (1535/1615 approx.) founded the Academia Secretorum Naturae (Academy of Nature's Secrets), thought to be the first academy of science in the world.

1564

Galileo Galilei (1564/1642) was born in Tuscany in Italy. Galileo learned about Aristotelian physics at the university of Pisa, but he soon began to question Aristotle's approach. Aristotle had a qualitative and verbal approach, but Galileo preferred a quantitative and mathematical approach to learning.

Aristotle believed, and argued without any evidence, that heavy bodies fall faster than light ones. Later on Galileo followed the example of Simon Stevin in Flanders who had dropped two objects from a high place and noticed that they both hit the ground so closely together that he couldn't notice any difference between the sounds they made when they arrived at the ground.

Galileo championed the astronomical ideas of Copernicus, who promoted the idea that the Earth moved around the Sun. This was in disagreement with the belief, strongly argued by Aristotle, that the Earth was the centre of the Universe and that the Sun went around the Earth every day.

Unfortunately for Galileo, the Catholic Church agreed with Aristotle's conjecture, so Galileo was eventually forced to recant his heliocentric ideas – with the Sun in the centre of the solar system – and was condemned to spend the last years of his life under house arrest on orders of the Catholic Church Inquisition.

Galileo is now described by Wikipedia like this:

> *Galileo has been called the 'father of modern observational astronomy', the 'father of modern physics', the 'father of science', and 'the father of modern science'.*

1569

Mercator, drew a world globe map with the longitude marked in 180 degrees East and West, and with latitude marked from 0 degrees to 90 degrees from South to North. After correcting some errors this gave us a map where every point could be described in terms of degrees of latitude and longitude.

Mercator used Ptolemy's method of dividing degrees so that each degree of longitude had divisions of 60 miles equal to a statute nautical mile, and each nautical mile was again divided into 60 units called minutes, and each minute was again divided into 60 units called seconds.

1574

Citizens in London complained:

> *The weights used throughout this our realm are uncertain and varying one from another, to the great slander of our realm.*

1581

Galileo began his studies of medicine in Pisa.

1582

Queen Elizabeth I (reigned 1558/1603) appointed a jury '*to sort out*' England's weighing and measuring problems. The 21 men on the jury failed to agree on better methods, so she appointed a second jury. It took them 6 years to arrive at a solution (see 1588).

Johannes Kepler (1571/1630) developed his pendulum theory, that it was the length of the pendulum that was related to the time for each swing; the mass on the end of the pendulum was unimportant.

1582 February 24

The Gregorian calendar was introduced because the old Julian calendar year had been slightly too long and this caused a drift of the seasons because, in the Julian calendar, all years exactly divisible by 4 were leap years.

To counter this trend a Calabrian doctor Aloysius Lilius devised a new calendar with these rules:

> *Every year that is exactly divisible by four is a leap year, except for years that are exactly divisible by 100; the centurial years that are exactly divisible by 400 are still leap years. For example, the year 1900 is not a leap year; the year 2000 is a leap year.*

The changes made by Aloysius Lilius also corrected the drift in the civil calendar by dropping 10 days to bring the calendar back into synchronization with the seasons.

Because Pope Gregory XIII formally decreed the new calendar it is known as the '*Gregorian calendar*'. There are others, but the calendar developed by Aloysius Lilius is the most widely used calendar in the world today. Although Aloysius Lilius went close to aligning the calendar with the length of the true year it still moves slightly. A recent suggestion is to make years that are divisible by 4000 normal years, rather than leap years, to improve the accuracy of the calendar.

1584

The Flemish engineer and surveyor, Simon Stevin (1548/1620), working from Brugge in Belgium, published a set of tables for working out the amount of interest that banks should charge for lending money. As he was working out these tables he realised that decimal numbers could make all calculations in all areas of life much easier. Stevin came to believe that the use of decimals could rid the world of the cumbersome common, or vulgar, fractions with all of their various calculating difficulties.

1585

Simon Stevin published two books that were essentially the same. *De Thiende* (Of Tenths) was written in Flemish and *La Disme* (The Tenths) was written in French. These were decimal arithmetic books in which Simon Stevin described the use of decimal numbers. These were the first books where the simplicity of decimal numbers was fully explained. Because of these books, the invention of decimal fractions is often attributed to Simon Stevin.

Although decimal fractions had been invented, lost, then re-invented several times previously, they had never been in widespread use. Common fractions and hexadecimal fractions were also available, but these were regarded as difficult to use. Clearly, Simon Stevin had in mind that decimal numbers could be used for all crafts, trades, and professions when he wrote the dedication to his two books on '*Tenths*':

> *Simon Stevin wishes the stargazers, surveyors, carpet measurers, body measurers in general, coin measurers and tradespeople good luck.*

Simon Stevin was born in Flanders (Belgium) but spent his adult life in the service of the Republic of the Netherlands. He was a military engineer and tutor in mathematics, and adviser in finance and navigation to the rulers William of Orange and Maurice of Nassau. He organized the school of engineering at the University of Leiden and wrote textbooks on engineering and bookkeeping as well as arithmetic.

Stevin explained in very definite terms the advantages to be gained by using decimal fractions in all mathematical operations and those to be derived from the decimal subdivision of the units of length, area, capacity, money value, etc.

Stevin states in his Introduction that the purpose of his books, *De Thiende* and *La Disme* is to teach the easy performance of '*all reckonings, computations, and accounts*' without common or vulgar fractions. He wrote that his book:

> ... *teaches us all calculations that are needed by the people without using fractions. One can reduce all operations to adding, subtracting, multiplying and dividing with integers.*

Stevin's technique was based on writing a whole number followed by the symbol '0' with a circle around it – here written as (0) – to represent the units, then each tenth of a unit is written as a single digit – possibly 0 – followed by 1 with a circle around it (1) then another single digit – possibly 0 – followed by 2 with a circle around it (2) and so on.

For example, the fraction 123 456/1000 would be written by Simon Stevin as: **123 (0) 4 (1) 5 (2) 6 (3).** Stevin called these decimal numbers and the symbols (1) etc signs. Now we would write this more simply as: **123.456 or as 123,456.** It depends on which decimal marker we choose, but it still means 123 456/1000.

Simon Stevin describes in his books how to add, multiply, subtract and divide decimal numbers. If you would like to learn more about Simon Stevin's decimal numbers and his decimal arithmetic you could start with an English translation of his books published by Robert Norton in 1608. You will find the complete text of Robert Norton's English translation at **http://adcs.home.xs4all.nl/stevin/telconst/10ths.html**

Although Simon Stevin suggested a number of decimal methods for various activities, he made no attempt at any coordination between them; he did not devise a decimal '*system*'.

Simon could see no reason why the following items could not be calculated using decimal numbers – immediately – in 1585.

- ⊇ Compilations of Land Meting – to be divided into decimal Rods and decimal Perches.
- ⊇ Measures of Tapestry or Cloth – to be divided into decimal Ells and Poles
- ⊇ Measures of Liquor vessels – 1 decimal Ame to be equal to 100 Antwerp Pots
- ⊇ Stereometry in General – to be divided into decimal Rods and Yards
- ⊇ On Astronomical Calculations – the circle to be divided into decimal angles
- ⊇ Moneymasters Merchants and all Estates in General – to be divided into decimal Pounds sterling, decimal Livres de gros and decimal Ducats.

The last of these was probably the suggestion that eventually led to the worldwide use of decimal money through the activities and leadership of Benjamin Franklin, Thomas Jefferson, and George Washington in the USA.

These suggestions would also appear to have been known to known to John Wilkins (1614/1672).

The following is a repeat of paragraph three, page one, this article:

… a 'universal measure' was first described by John Wilkins in London.

Go to the article Commentary on 'Of Measure' by John Wilkins for a better understanding of how the work of John Wilkins, AN ESSAY Towards a REAL CHARACTER, And a PHILOSOPHICAL LANGUAGE (1668), fits into an historical context.
Wilkins' Essay shows that the metric system and the International System of Units (SI) both had their origins in England in 1668.

In her 1969 biography of John Wilkins: *John Wilkins 1614/1672 An Intellectual Biography* (University of California Press 1969), Barbara J. Shapiro makes it clear that Wilkins knew about Simon Stevin's work. She said:

> *He seems to have been familiar with the most advanced work in the field, including that of Galileo and Simon Stevinus.*

Other contributions to the modern world made by Simon Stevin were the introduction of double-entry bookkeeping, the replacement of the sexagesimal system by the decimal system for almost all measurement, and his opposition to the exclusive use of Latin in scientific writing; after 1583 he published only in Flemish or French.

1586

Simon Stevin's name became prominent in the history of science when he dropped two spheres of lead, one ten times the mass of the other, from a height of about 10 metres onto a piece of board. Stevin and his friends noticed that the sounds of the balls striking the board were almost simultaneous.

1588

Elizabeth I issued a new standard yard that remained the legal British yard until 1824, when an Act of Parliament under George IV superseded it. This Act attempted to introduce systems of measures more widely into British society and remove inaccuracies associated with measurement.

The new standards, made for length and for mass, were cast in metal and 57 copies of the standards were made for keeping in market towns all around the nation. Precious metals and stones, however, were still to be weighed in '*grains*'.

One of these standards, a new standard yard, consists of an iron bar with a square cross section, about 13 millimetres on each side. The standard yard was the distance between its ends. This was the legal British yard for more than 300 years even though, sometime between 1760 and 1819, it was broken and repaired.

This bar still exists in the Science Museum in London and it has been measured at 914.15 millimetres – a little shorter than the (1959) International standard yard that is now based on metric system units (that is 914.40 millimetres exactly).

1591

Aristotle had believed, and argued without any evidence, that heavy bodies fall faster than light ones. In 1591 Galileo followed the example of Simon Stevin in Flanders. Stevin had dropped two objects from a high place; because they hit the ground so closely together, Stevin could discern no difference between the sounds they made when they hit. Galileo repeated Simon Stevin's experiment when he dropped weights of different sizes from a tower in Pisa.

1593

The term '*statute mile*' originated with Queen Elizabeth I, who changed the definition of the mile from the Roman mile of 5000 feet to 5280 feet or 1,760 yards or 63,360 inches by issuing a statute. This was largely irrelevant until the USA decided to issue their own statute mile by redefining the length of a statute foot for the USA as 1200/3937 metre or 0.3048006096 metres approximately. Since then it has been agreed to define the length of a mile as exactly 1.609 344 kilometres. This is known as the international mile.

The statute mile was divided into eight furlongs, the length that a furrow could be ploughed before the ox or oxen had to be rested (the word *furlong* is a contraction of the words 'furrow long'). A furlong was defined as 40 rods long; each rod was defined as 5½ yards; each yard was three feet, making up 5280 feet to one Queen Elizabeth I mile (depending on the length of the 5280 feet). Since 1593 the length of the mile (and all of the other old pre-metric measures mentioned here) has changed whenever the definition of the yard and the foot changed. Currently, the mile used in the UK is a '*metric mile*' as it is based on the length of the metre; the *metric mile* is exactly 1609.344 metres long.

Around this time Galileo invented a thermometer for measuring temperatures, based on the expansion and contraction of air enclosed in a glass container.

1595

Bartholomaeus Pitiscus (1561/1613) used a notation for his trigonometrical tables that included the idea of a decimal point. This is considered to be the first use of the decimal point that we now all use quite regularly.

The English Parliament voted to make an English mile equal to exactly 5280 feet so that it would be exactly 8 furlongs in an English mile.

1597

Juan Fernandez de Velasco, the Governor of Lombardy, ordered the standardization of all local measures according to the Milanese standard. All attempts to carry out his reform failed so badly that his successor, de Fuentes, called it off in 1605 and before long, the matter was forgotten.

Henry Briggs (1561/1630) was the first Gresham Professor of Geometry; he worked on astronomy, navigation, and on devising mathematical tables for finding such things as the height of the pole star and eclipses. He also invented the method of long division using decimal numbers that many of us learned at school.

1600

Francois Viéte (1540/1603) advocated the use of decimal numbers using a comma ',' as the decimal marker (he called it the separatrix) with an underbar for the fractional part. Here is an example: **1234,<u>5678</u>.** He also suggested the decimal division of degrees, minutes, and seconds for measuring angles.

1602

Galileo discovered that the longer the string on a pendulum, the slower it swung, and the width of the pendulum's arc or of the weight of the pendulum bob made little difference to the time of the swing. That is, the period of a pendulum (the time it takes for pendulum to swing back and forth) depends almost solely on the length of the pendulum. The tradition is that Galileo first began to think about the motion of pendulums as he watched suspended lamps swinging back and forth in the cathedral of Pisa instead of attending to the church service.

One of Galileo's most significant observations was based on his studies of the pendulum. In Pisa, Galileo found the exact length for a pendulum to swing through its arc in exactly one second. This became known as a '*seconds pendulum*'. A seconds pendulum is a pendulum whose period is exactly two seconds; one second for a swing in one direction and one second for the return swing.

We now know that a seconds pendulum varies according to where it is on the Earth. For example at the equator the seconds pendulum is 991 millimetres long, at the North Pole it is 996 millimetres and at 45° North of the equator it is in between, at 994 millimetres. The pendulum is mentioned in two of Galileo's books: *Dialogue Concerning the Two Chief World Systems* (1632) and *Dialogues Concerning Two New Sciences* (1638).

Galileo suggested that a more accurate clock might be made using his observations of pendulums but, like Leonardo da Vinci before him, he never got around to making one.

The idea of a fixed standard length for a clock pendulum proved to be particularly intriguing for scientists at that time. Galileo's discovery spread quickly throughout the world, especially in Europe, and soon led to further study of time intervals and the development of pendulum clocks; most of the '*long-case*' models were made with a pendulum that was close to being one metre long.

1603

Federico Cesi founded the Accademia dei Lincei, in Rome, for the study of mathematics and natural sciences. See **http://www.lincei.it**

Johann Hartmann Beyer (1563/1625) published a book, *Logistica Decimalis*, in which he claimed to be the inventor of decimal numbers.

1608

When Simon Stevin's book was translated into English, Robert Norton, an '*engineer and gunner*', gave it the title **'Disme: The Art of Tenths'** or '**Decimall Arithmeticke**'. From this title, the USA eventually used the word 'Disme' (without the silent internal 's') as the name of the coin that is a tenth of a dollar. The dime in the USA is quite likely the world's only coin named after a book! You can read Robert Norton's translation at **http://adcs.home.xs4all.nl/stevin/telconst/10ths.html**

1609

Johannes Kepler published his Laws of Planetary Motion.

Galileo began to use the telescope, developed by Lippershey in 1608, for astronomy.

1610

Galileo discovered Jupiter's moons, sunspots, and stars in the Milky Way Galaxy.

1613

Richard Witt published another English translation of Simon Stevin's *Decimal oArithmetic*.

1614

The Estates General met in France. This meeting consisted of the three French Estates.

- ⊇ The first estate was the church;
- ⊇ the second estate was the nobles;
- ⊇ the third estate was the commoners.

The Scottish laird John Napier, Laird of Merchiston (1550/1617), developed logarithms. These were designed to replace lengthy calculations using multiplication and division with easier calculations using addition and subtraction. At Gresham College in London, Henry Briggs was enthusiastic about the:

> *... new and remarkable logarithms. I never saw a Book which pleased me better or made me more wonder.*

John Wilkins (1614/1672) was born at Fawsley, Northamptonshire. His father was a goldsmith, and his grandfather a vicar.

1615

John Napier used a comma as a decimal marker to separate the whole number part from the decimal number part in his book, *Rabdologia*. He used a comma in his early works and then later changed to using a dot as his decimal marker.

1616

When Edward Wright translated John Napier's book, *Descriptio* from Latin to English, he also improved on Napier's and Stevin's notations of decimal numbers. It is Wright's decimal notation complete with the decimal point "." that he used in his *A Description of the Admirable Table of Logarithms* that we all now use.

1617

Willebrord Snellius, (1580/1626), an astronomer and mathematician from Leiden in the Netherlands made the first calculations of the length of the Earth's meridian.

1619

Henry Lyte published another English translation of Simon Stevin's *Decimal Arithmetic*. He also proposed that decimal currency should be linked with decimal weights and measures.

1620

Edmund Gunter (1581/1626) published his *Canon Triangulorum*, describing several measuring instruments that he had invented, including what has become known as 'Gunter's chain'. This was based on Simon Stevin's decimal arithmetic, in that it had 100 links to facilitate the use of decimal arithmetic to make relatively complex trigonometric calculations. He also developed '*Gunter's scale*', a ruler with lines to show the logarithms of trigonometric functions, invaluable to people such as surveyors who constantly needed triangulation calculations. After 1620, a furlong was defined as ten lengths of Gunter's chain, and the chain had 100 links that were each 7.92 inches long.

It is interesting that Edmund Gunter's base in London, Gresham College, was the same college where John Wilkins worked in the 1660s. Presumably Gunter was familiar with Simon Stevin's work on decimal arithmetic, translated into English as *Decimall Arthmetike* in 1608. At Gresham College in the 1660s, John Wilkins would have been familiar with Gunter's decimal work, and the decimal work of Simon Stevin, as he formulated his ideas for a *universal measure* based on decimal numbers.

Cornelius Drebbel von Alkmaar (1572/1633) invented a thermometer using alcohol in a glass tube. Drebbel was from the Netherlands but he lived much of his life in London. He carried out many experiments in optics and heat, and he could demonstrate lightning and rain at will. He is regarded as a pioneer in the area of temperature control and measurement systems, and invented or developed:

> *improved versions of the telescope, barometers, camera obscura, microscopes, an incubator for chickens, a solar powered energy system, air conditioning, and an oven with a smart thermostat.*

1624

Henry Briggs found that Napier's logarithms were too difficult to work with in their original form. After he visited Napier in Edinburgh he soon devised a new form of logarithms, his '*logs to base 10*', in which to multiply two numbers we simply add their logarithms.

In his *Arithmetica logarithmica* he published his extensive hand-calculations of the logarithms of 30 000 numbers to 14 decimal places, and these proved to be of enormous value to mariners and navigators.

1627

In the city of Ulm in Germany, Johannes Kepler suggests that an oak tank be made that would be able to define the measures (capacities) that were valid in that city.

1630

The invention of logarithms by Napier and their development by Briggs quickly led to the development of many instruments based on a logarithmic scale. Most notable was the slide rule that was widely used for over three hundred years, until the invention of the pocket calculator at Texas Instruments in 1966.

1631

Pierre Vernier (1580/1637) invented a device to add to a theodolite. He published this in Brussels as *La construction, l'usage, et les propriétés du quadrant nouveau de mathématiques* (*The Construction, Use, and Properties of the New Mathematical Quadrant*). His device later became widely known as the Vernier scale and its principle was applied to a wide range of measuring instruments. Vernier's development attached a movable ring that, although divided into thirty equal parts, was actually thirty-one half degrees in length. It was placed so that it was aligned next to the initial scale, that was also divided into thirty parts, but was actually thirty degrees in length. To measure an angle precisely to the nearest minute of arc, you simply had to note which division line of the Vernier scale coincided with which division line of the theodolite. This gave a precisely measured angle in degrees and minutes.

Pierre Gassendi (1592/1655) observed the transit of Mercury that had been predicted by Johannes Kepler.

1632

Galileo published *Dialogo dei due massimi sistemi del Mondi* (*Dialogue Concerning the Two Chief World Systems*). In this he compared the Sun-centred and the Earth-centred ideas of astronomy.

1634

Richard Witt published *An Analysis of Stevin's Disme* (on decimal arithmetic).

1636

Marin Mersenne (1588/1648) measured the speed of sound by calculating how long it took for an echo to return over a known distance. His speed of sound was within 10% of the modern value of 343 metres per second or 1236 kilometres per hour.

1637

John Wilkins became vicar of his hometown, Fawsley, but later resigned to become personal chaplain to various Lords, Princes, and eventually Charles Louis, nephew of King Charles I and afterwards Elector Palatine of the Rhine.

1638

Publication of John Wilkins' scientific treatise, *The Discovery of a World in the Moone*. in which Wilkins describes a trip to the Moon.

Galileo published *Dialogues Concerning Two New Sciences*.

1639

William Gascoigne (1612/1644) used a micrometer screw gauge to measure the diameter of the Sun and the planets as viewed through a telescope.

1639 December 4 15:15

Jeremiah Horrocks (1618/1641) observed the transit of Venus across the face of the Sun. His observations allowed him to calculate the distance of the Sun from the Earth. His estimate of 96 million kilometres was a long way short of the current value of 150 million kilometres but it was the best estimate made up to that time.

1640

Publication of John Wilkins' *A Discourse Concerning a New Planet*. This book included a reprint of his earlier book, *Discovery of a World in the Moone*.

1641

John Wilkins anonymously published the first English language book on cryptography – secret writing in code. It was a small but comprehensive work called *Mercury, or The Secret and Swift Messenger*.

A Scottish measurement law attempted to produce national Scottish standards to facilitate local and intercity trade.

1642 December 25

Isaac Newton (1643/1727) was born at Woolsthorpe. It is said that he was born 'prematurely and posthumously'. Prematurely because he was small enough to fit into a small 'quart pot' (about a litre) which suggests that his birth mass was a lot less than the 2500 grams used to define modern babies as premature; his survival was in question for some time. Posthumously because his father died three months before Isaac was born.

1643

The mercury barometer was invented by an Italian, Evangelista Torricelli (1608/1647), a pupil of Galileo . Athanasius Kircher (1602/1680) invented the mercury thermometer.

1644

Blaise Pascal (1623/1662) announced a decimal adding machine for the new decimal French currency that he called a 'Pascaline'. His design was very practical and some examples were still in use up to the 1960s, after which electronic calculators took their place. The Pascaline could add up to 10 digit numbers and could 'carry' numbers from one column to the next.

Marin Mersenne (1588-1648), a French priest, recruited teams of monks to count the swings of a seconds pendulum continuously for 24 hours. They found the length of the seconds pendulum was 994 mm (about 36 91/128 old French inches).

1645

Tito Livio Burattini (1617/1681) published the book, *Bilancia Sincera* (*The Honest Balance*) that improved on the hydrostatic balance invented by Galileo. Burattini was born in Italy but spent most of his life in Poland, where he worked as an architect for the king. He had previously travelled to Egypt where he studied the obelisks in Heliopolis and Alexandria.

1648

Tito Livio Burattini designed a flying machine but didn't build it.

John Wilkins published *Mathematicall Magick*, the first book on mechanics ever written in English. In this book John Wilkins describes a number of mechanical inventions and devices that he owned. There are descriptions of clocks, flying machines, submarines, and perpetual motion machines moved by means of magnets. *Mathematicall Magick* also includes general discussions of mechanics, including descriptions of the physical principles that underlie the use of levers, pulleys, screws, wheels, and wedges.

1648 to 1659

John Wilkins was appointed Warden of Wadham College, Oxford. Under his direction the college prospered because, even though he was a supporter of Oliver Cromwell, he remained in touch with his former Royalist friends who placed their sons in his charge at the College.

1655

Isaac Newton went to live with an apothecary, Mr Clarke, so he could attend the Grammar School at Grantham.

Christiaan Huygens (1629/1695), a Dutch horologist, observed the rings of Saturn.

1656

John Wilkins married Robina Cromwell, Oliver Cromwell's sister.

Christiaan Huygens, who lived in the Netherlands but was not isolated from the world's scientific community, made the first clock that used a pendulum to measure time.

Stephen Hawking wrote an anthology, *God Created the Integers: The Mathematical Breakthroughs That Changed History*. The title refers to a quotation attributed to mathematician Leopold Kronecker. '*God made the integers; all else is the work of man*.'

Hawking wrote:

> *While in Amsterdam, (René) Descartes became friendly with Constantijn Huygens, secretary to Frederick Henry, Prince of Orange. Huygens came from a family of diplomats and he became an ardent supporter of Descartes. However, the Huygens family is best known for Constantijn's eldest son Christiaan (1629/1695) a contemporary of Newton who the English philosopher John Locke would describe as the 'Huygenius'. Descartes took an active interest in the education of the young Christiaan Huygens and Huygens developed Descartes' theory of vortices.*

1658 September 3

Oliver Cromwell died and was succeeded as Lord Protector by his son, Richard.

1659

Shortly before his death, Oliver Cromwell arranged John Wilkins' appointment as Master of Trinity College, Cambridge. This appointment was later confirmed by Richard Cromwell. Wilkins was Master of Trinity College, Cambridge, from 1659 to 1660.

The Italian mathematician, Tito Livio Burattini built a calculator with 18 disks. Some coupled disks used base 12, some used base 20, but there was no capacity to 'carry' numbers from one column to the next.

1660 November 28

Following a lecture by Sir Christopher Wren, a group of twelve met at Gresham College in London and decided to found 'a Colledge for the Promoting of Physico-Mathematicall Experimentall Learning'. They called it the *Society of London for the Improvement of Natural Knowledge* .

It later became the *Royal Society of London for the Improvement of Natural Knowledge* when King Charles II (reigned 1660/1685) became its patron, and later again simply the *Royal Society,* as it still is today.

The Royal Society is now regarded as one of the world's oldest learned scientific academies still in existence. As a voluntary organisation it serves as the academy of sciences for the UK.

John Wilkins chaired the first meeting and was the first secretary.

See **http://www.cl.cam.ac.uk/~rja14/wilkins/wilkins.html**

For those who are not familiar with John Wilkins, here is what Barbara J. Shapiro said about him in the introduction to her book, *John Wilkins 1614/1672 An Intellectual Biography* (University of California Press 1969):

> *For Wilkins had been in turn or in tandem theologian, scientific experimenter, Warden of Wadham College, Oxford, science-fiction writer, linguist, encyclopedist,*

scientific entrepreneur, and administrator, bishop, politician, and preacher. To say his fifty-eight years had been full ones would be to understate the case. It is not the fullness of his years, however, but their peculiar richness that makes John Wilkins a figure worthy of historical attention. Grant McColley once wrote that 'When a complete biography is prepared, it will be found, I suspect, that John Wilkins was the most dynamic force in seventeenth-century England.' His choice of words is apt. Not the greatest mind or the most influential scholar of the century, rarely a central figure in the political area, Wilkins nevertheless seems to have played a key role in each of the movements to reform and liberalize English intellectual life: first, the change from an authoritarian, dogmatic religious outlook to the more liberal, rationalistic credo of Restoration and eighteenth-century England; second, the scientific revolution that during the course of the century replaced the average man's traditional concept of the cosmos with that of Copernicus and to a more mechanistic concept of nature based on the findings of natural science; and third, though less important, the adaptation of simpler modes of intellectual communication.

Although not himself a major scientific innovator, Wilkins's popularizations of science were among the most widely read scientific works of the day in England. He was the nucleus of the group that for some years made Oxford the scientific center of the nation. And he was one of the principal founders and supporters of Oxford's successor as the national center of scientific learning, the Royal Society. In short, during and after the Civil War, Wilkins was England's single most influential and effective organizer and purveyor of the scientific culture.

One of the first actions of the *Royal Society* was to suggest that a universal measuring system should be based on the length of a pendulum that swung uniformly back and forth in one second. Christopher Wren (1632/1723) probably proposed this based on earlier suggestions by Huygens and Ole Rømer, who in turn had based their ideas on the Marin Mersenne's study of pendulums swinging, published in 1644.

From this simple idea, it was Wilkins' drive toward '*simpler modes of intellectual communication*' that led him to develop his '*universal measure*' that we now know as the International System of Units (SI) or simply as the '*metric system*' (see 1668 below). This idea for a *seconds pendulum* was again taken up in the 1780s by Thomas Jefferson (1743– 1826), later the third president of the USA.

The idea of a unit of length based on nature had been advocated for some time before Christopher Wren formally proposed it. Many scientists regarded the length of a pendulum oscillating with a given, well defined period as the natural choice for a unit of length based on nature.

Leonardo da Vinci had reported his original observations of the pendulum in 1452; Galileo Galilei discovered that the length of the string on a pendulum was most important to the time of the swing in 1602; Christian Huygens built the first practical pendulum clock in 1657; and many other experimental and theoretical scientists had also systematically studied the properties of the pendulum, so by 1660 it was considered that the pendulum's properties were well known.

1661

Marcello Malpighi (1628/1694) reported his observations of the capillary action in frog's lungs to the Royal Society. These observations were immediately recognised as the missing link in William Harvey's theory of blood circulation.

1661 June 5

Isaac Newton began his studies at Trinity College, Cambridge.

1662

John Wilkins became Vicar of St Lawrence Jewry in the heart of London.

Christopher Merrett (1614-15/1695) wrote to the Royal Society about a technique he had devised for double fermentation to produce sparkling wine. Later this became known as the '*méthode Champenoise*' or the '*champagne method*' when it was used to found a regional industry in France.

1663

Modern archaeology began when Charles II, with his physician Walter Charleton and John Aubrey studied the Neolithic stone circle at Avebury in Wiltshire. They submitted drawings from their studies to the Royal Society.

1664

Sir Samuel Morland (1625/1695) constructed a decimal calculator in England that was an improvement on Pascal's adding machine. It used a stylus to input numbers and could 'carry' numbers from column to column.

Robert Boyle (1627/1691) published his book of *Experiments and Considerations Touching Colours*.

1665

Gabriel Mouton (1618/1694), a country vicar and choirmaster, repeatedly counted and recorded the swings of a pendulum to establish the relationship between the length and the time for each swing. Later a device was made of a length such that the pendulum would beat a second of time; it became known as a '*seconds pendulum*'.

The Royal Society published *Micrographia* by Robert Hooke (1635/1703). This book contained many drawings made using a microscope and included Hooke's famous drawing of a flea. Hooke's book was the first to use the word 'cell' as a biological term.

Christiaan Huygens suggested using the freezing and boiling points of water as standards for a thermometer temperature scale.

Isaac Newton differentiated between spherical aberration and chromatic aberration in a glass lens. He then pointed out that it was impossible to eliminate or suppress chromatic aberration in any optical system consisting of lenses. It wasn't until 1758 that an English optician, John Dollond (1707/1761) invented achromatic lenses.

Plague appeared in London. Because it was detected by the colour of the lumps that appeared on its victims, people called it the Black Death. It is thought that the plague germs were carried by fleas that lived as parasites on rats.

1665 January

Isaac Newton finished his Bachelor's Degree at Trinity College, Cambridge.

1665 August

Isaac Newton moved back to Woolsthorpe from Cambridge due to the Plague. He continued his mathematical and scientific work at his mother's home.

1666

The Great Fire of London burnt down extensive portions of the central parts of the city.

The French join the Dutch in the war against the English.

Samuel Morland showed a new calculator for English currency that was similar to the Burattini calculator of 1659. Morland's calculator could add pennies and shillings and pounds separately but because it was not working with a decimal currency, it could not 'carry' from one unit to the next.

John Wilkins became vicar of Polebrook in Northamptonshire, the same year that the church where he had been vicar and would be buried, the Church of St Lawrence Jewry in London, was badly burned in the great fire of London. Later, between 1670 and 1687, Christopher Wren rebuilt this church. Christopher Wren's associate on rebuilding London after the great fire of London was Robert Hooke.

This was also the time that John Wilkins learned of the modern concept of having a back-up copy; all but one of his draft copies of '***An Essay Towards a Real Character and a Philosophical Language***' (see 1668 below) were lost in the great fire of London. Without Wilkins' *Essay* we may never have developed a decimal metric system.

Jean-Baptiste Colbert (1619/1683) founded the French *Académie des Sciences* (*Academy of Sciences*). This society had the task of encouraging and protecting the spirit of French scientific research. As one of its members was King Louis XIV (reigned 1643/1715) , its first meeting was held in the King's library. Unlike the Royal Society in England, the French Academy of Science was founded to be an important part of the French government and in this sense it was not an independent organisation. It was to be apolitical and not discuss religious and social issues. As one of the earliest academies of sciences, it led many of the scientific developments in Europe in the 1600s and 1700s.

1667

King Louis XIV founded the first national institution for measurement, the Paris observatory, focusing on issues related to astronomy, navigation, and surveying.

John Milton published *Paradise Lost*.

1667

John Wilkins became bishop of Chester, a post he kept until his death in 1672.

1667 October 2

After Isaac Newton returned to Cambridge he was elected a minor Fellow of Trinity College and wrote *Enumeratio curvarum* (The *Enumeration of Cubics*).

1668

The Royal Society published '***An Essay Towards a Real Character and a Philosophical Language***' by John Wilkins. In it he attempted to create a universal, completely unambiguous language with which scholars and philosophers could communicate easily and clearly. Wilkins' 638 page essay included a four and a half page description of a measurement system that included his ideas for a '*universal measure*' that could be used for length, 'weight', capacity, and money.

Wilkins short proposal for a '*universal measure*' contained almost all of the elements of the International System of Units (SI), the modern metric system. He suggested:

⊇ a *universal* standard of length,

⊇ a '*universal measure*' based on a measurement of the Earth or on the length of a pendulum beating in one second,

⊇ the '*universal measure*' of standard length to be used to define area, volume, and 'weight' using distilled rainwater, and

⊇ a decimal system to divide large units or to multiply small units.

Wilkins' *Essay* is the first description of a complete system of measurement intended to be used by the whole world. He seemed to have understood the need for standards for units of measurement that could be agreed internationally. Clearly, the metric system and the International System of Units (SI) had their origins in England.

Although Wilkins' plan was not acted on, in retrospect it is easy to see it as the first statement of an international system of measurement, that led in time to the decimal metric system that was legalised in France in the 1790s, more than 100 years later.

Progress of the metric system has proved to be inevitable, even though Wilkins himself was not confident of its success. He wrote about his plans for a *universal measure*:

I mention these particulars, not out of any hope or expectation that the World will ever make use of them, but only to show the possibility of reducing all Measures to one determined certainty.

Later, the development of Wilkins' ideas into what became the metric system in France in the 1790s was heavily influenced by thinkers in the USA, especially the decimal ideas promoted by Benjamin Franklin, Thomas Jefferson, and George Washington.

Following the publication of John Wilkins' *Essay,* many other people in several countries seemed to take up and promote themes that appeared in it. Here is an extract from *John Wilkins 1614/1672 An Intellectual Biography* by Barbara J. Shapiro (University of California Press 1969):

Some of the greatest minds of the century received Wilkins's efforts warmly. Newton, who at one time had attempted a similar scheme, mentioned Wilkins's work in his correspondence. John Locke, too, was interested in Wilkins's work, and recommended his book on the subject in preference to Dalgarno's. Contemporaries such as Sir William Wotton even saw a connection between the work of Wilkins and that of Locke, and suggested that any one wishing to pursue the subject of a universal character beyond Wilkins should consult Locke's 'An Essay Concerning Human Understanding'. Leibnitz was very interested in a universal character, and was familiar with the work of both Wilkins and Dalgarno. One recent writer has suggested that they, rather than Leibnitz, should be credited with the important developments in symbolic logic that resulted from the search for a philosophic language. Wilkins's Essay, although written in English, quickly found its way abroad. Comenius was sent a copy by Oldenburg. Wallis sent one to the Italian physicist Giovanni Borelli. Huygens and Leibnitz obtained copies. The Elector Palatine, Wilkins's former patron, tried to obtain a copy, and Thomas Pigot, one of the Aubrey circle, was hopeful that the Elector would 'be very instrumental' in promoting Wilkins's design in his domains. A Latin edition was prepared to make the work more widely available, but it was never printed. Efforts were undertaken to translate the Essay into French as well.

As concrete examples of the spread of Wilkins' ideas, they were repeated by Gabriel Mouton in 1670, Jean Picard (1620/1682) in 1671, and Gottfried Leibniz (1646/1716) in 1673 – see below. The word ‘metre’ probably derived from a translation, by Tito Livio Burattini in 1675, of Wilkins’ words '*universal measure*' into the Italian words, '*metro cattolico*', seven years after the publication of the ‘*Essay’* (see below). More information about the life of John Wilkins can be found from Aubrey's *Brief Lives* at **http://www-history.mcs.st-andrews.ac.uk/history/Societies/Aubrey.html** where it is written:

He was no greatly read man; but one of much and deep thinking, and of a working head; and a prudent man as well as ingenious. He was one of Seth, Lord Bishop of Salisbury's most intimate friends. He was a lusty, strong grown, well set, broad-shouldered person, cheerful, and hospitable.

He was the principal reviver of experimental philosophy (in the spirit of Lord [Francis] *Bacon) at Oxford, where he had weekly an experimental philosophical [scientific] club, which began 1649, and was the cradle of the Royal Society. When he came to London, they met at the Bull-head tavern in Cheapside (e.g. 1658, 1659, and after), till it grew too big for a club, and so they came to Gresham College parlour.*

From John Aubrey's *Brief Lives* (Edited by R Barber, Boydell Press, 1982)

Other good references about the life and times of Bishop John Wilkins can be found at: **http://www.cl.cam.ac.uk/~rja14/wilkins/wilkins.html and http://www-history.mcs.st-andrews.ac.uk/history/Biographies/Wilkins.html**

The modern English translation from 17th century English of the pages relevant to measures from Wilkins' *Essay* can be found in the article *Translation of Wilkins' Essay*.

The French King Philip I (reigned 1668/1671) redefined the French *toise de Charlemagne*. This toise had been a length standard in France since the time of Charlemagne (reigned 768/814). The toise was situated on the outside of one of the pillars of the old Châtelet building. This old standard (*étalon*) was still on that pillar in 1714. Like many of the other toises of length in France the *toise de Charlemagne* was about 1.95 metres long.

Isaac Newton devised successful methods for casting and polishing mirrors of the best shape to use in a reflecting telescope. His first reflector telescope was 160 millimetres long with a mirror 31 millimetres across.

1668 March 16

Isaac Newton was elected as a major Fellow of Trinity College, Cambridge.

1668 July 7

Isaac Newton was granted a Master's Degree at Cambridge.

1668 August 5

Isaac Newton made his first visit to London.

1669

Giovanni Domenico Cassini (1625/1712), an Italian astronomer and mathematician, travelled to France to work with Christiaan Huygens (1629/1695), the man who invented the pendulum clock, and Adrian Azout, to help develop better scientific instruments. He became a French citizen and was known as Jean-Dominique Cassini. Their observations and better instruments made it possible to measure the movements of the moons of Jupiter and to see the rings of Saturn. The rings of Jupiter became important later to measure time accurately to determine the lines of longitude on the Earth's surface.

Jean Picard (1620/1682) commenced work to correct the known size of the world after copies of the lost scrolls of Eratosthenes were discovered in Constantinople by Polish researchers. Using trigonometrical methods, he set out to establish an accurate distance from Malvoisine to Sourdon, a distance of about 200 kilometres.

French mathematician Gilles Personne de Roberval (1602/1675) invented the weighing balance that bears his name. The Roberval balance was an improvement on earlier balances as it prevented the pans or platforms from tilting as they moved up and down making sure that the position of weights on the pans had no effect on the way it balanced.

1669 February 23

Isaac Newton described his reflecting telescope in a letter to Henry Oldenburg, first Secretary of the Royal Society.

1669 October 29

Isaac Newton elected Lucasian Professor of Mathematics at Trinity College Cambridge.

1670

Jean Picard completed a measurement of an arc of a meridian of the Earth to determine the distance of a degree of arc on the Earth's surface. He had measured the distance from Malvoisine to Sourdon, a distance of about 200 kilometres, and was accurate to within about 3 metres (or 0.015%). Prior to this, the wrong calculation devised by Ptolemy for the circumference at the equator had been about 30 000 km instead of 40 000 km now established. Picard went on to calculate the diameter of the Earth as 12 744 kilometres, which is very close to the modern equatorial diameter now known to be 12 756 km.

Picard worried that he could lose his standard measuring rod, called a toise in French. He conceived the idea of comparing his standard toise with the length of a simple pendulum beating in seconds. He reasoned that he could then reproduce a standard toise if he ever needed a new one. This eventually led to the idea of a standard unit of length based on a *seconds pendulum* beating one second at sea level, at a latitude of 45°.

Gabriel Mouton was Vicar of St. Paul's Church in Lyons, France, with a doctorate of theology from Lyon University. He was also interested in mathematics and astronomy, and promoted a decimal measurement system that had many similarities to the system proposed two years earlier by John Wilkins (see 1668) .

Mouton published his ideas in a book called, *Observationes diametrorum solis et lunae apparentium* (*Observations on the Apparent Diameter of the Sun and the Moon*). He explained the advantages of a system based on nature rather than the length of a king's foot, and proposed a linear scale based on a geodetic minute to be divided decimally.

Mouton wanted to base a '*universal measure'* on the circumference of the Earth. Picard's estimates of the earth's circumference had recently become available, so Mouton also worked out the size that he would need to make a pendulum, so that the size of the Earth could be referred to by using a pendulum as a convenient and easy everyday standard. Mouton did not use Picard's estimate of the Earth's circumference. He based his calculations in his book on the measurements of the size of the Earth conducted by Giovanni Battista Riccioli of Bologna (1598/1671) an Italian astronomer. We now know that Riccioli's figures were mistaken because his methods have since proved to be faulty.

Mouton proposed a standard length based on a 1/10 000 of a minute of arc. Mouton's pendulum, located in Lyon, oscillated 3959.2 times in an hour and so was not a seconds pendulum. Using back calculation, Mouton's pendulum would have been close to 205 mm long. (There are actually two possible seconds pendulums, depending on whether you measure the period – forward and backward movement gives a pendulum about 249 mm long – or only half the period – only forward or only backward that gives a pendulum about 994 mm long. Eventually, there was agreement in naming the longer seconds pendulum as the one that gave a second in a single swing of the pendulum, that is the 994 mm pendulum.

Mouton suggested that the minute of arc along a meridian be measured and defined as a unit called a 'milliare'. He then suggested a decimal system of measurement dividing the milliare into centuria, decuria, virga, virgula, decima, centesima, and millesima by successively dividing by factors of ten. In short, Mouton suggested that, using decimal divisions, we could use Simon Stevin's 1585 decimal system of tenths to divide an Earth-based unit into smaller parts. Mouton's milliare corresponded to a nautical mile of exactly 1852 metres and his virga would, by his definition, have been exactly 1852 millimetres.

Mouton's ideas attracted interest at the time, and were supported by Jean Picard as well as Huygens in 1673. They were also studied at the Royal Society in London, which had commissioned the original work by John Wilkins in 1668. In 1673, in Germany, Gottfried Leibniz independently made similar measurement proposals to those of Wilkins.

It would be over a century later, however, that the French Academy of Sciences weights and measures committee suggested the decimal metric system that initially defined the metre as a decimal division of a quadrant of the Earth.

1671

For over a century, the length of a seconds pendulum had periodically been proposed as a way of establishing a standard length. In 1671, Jean Picard, in his book, *Mesure de la terre* (*Measure of the earth*), proposed defining the French foot, *pied or* '*universal foot*' as a third, and the toise as twice the length of the seconds pendulum.

At this time, it was the seconds pendulum that had most consensus between scientists.

Jean Picard, Olaus Rømer (1644/1710), and other astronomers promoted the idea that the length of a pendulum beating in seconds should be used as a standard unit of length for all nations.

They suggested that a pendulum of specified time period could be used as a convenient sub-multiple for people to use routinely as an everyday standard for length.

Picard specifically suggested a *universal foot*, to be represented by one-third of the length of a pendulum beating exactly in seconds. However, it was already known that identical pendulums set up in different places had different periods of oscillation, so any such definition would also have to have a specific location for the standard pendulum.

The issue of a *specific location* was fraught with political problems. Everyone – France, UK, and USA wanted the *specific location* to relate specifically to their own country.

1671 December

Isaac Newton sent his reflecting telescope to the Royal Society. Since then reflecting telescopes have often been called *Newtonian* telescopes.

1671 December 21

Isaac Newton was proposed for election to the Royal Society in London.

1672

Isaac Newton reported new ideas on the nature of light and colour. He had noticed that when two flat pieces of glass were pressed together, he could see circular bands of rainbow-like colours. These came to be called *Newton's Rings*.

Although Newton did not recognize it immediately, he had discovered a very precise method for making accurate measurements. Later, other scientists were to use *Newton's Rings* to develop and establish a new branch of science called interferometry. Now, interferometry is routinely used to measure distances down to nanometres.

Thomas Gobert built the Trianon de Saint-Cloud (later to be known as the Pavillon de Breteuil) for Monsieur, the brother of King Louis XIV, who inaugurated the building.

Jean Richer (1630-1696) discovered that the force of gravity was not uniform around the world. He made this discovery by comparing the swing of a pendulum at the Observatory in Paris (45 °N) with the same pendulum in Cayenne, which is quite close to the equator.

1672 January 11

Isaac Newton was elected as a Fellow of the Royal Society of London.

1672 February 6

Isaac Newton's first letter on *Light and Colours* was read to the Royal Society where Robert Hooke, a respected senior scientist and Curator of Experiments for the Royal Society, criticized it harshly.

1672 February 8

Isaac Newton published his first scientific article, a letter on *Light & Colours,* in the Philosophical Transactions of the Royal Society.

1672 March 25

An account of Isaac Newton's new reflecting telescope was published in the Philosophical Transactions of the Royal Society.

Seven additional optical papers by Isaac Newton also appeared in the Philosophical Transactions throughout this year.

1672 November 19

John Wilkins died in London and was buried in the church of St Lawrence Jewry.

1673

The Dutch mathematician, astronomer and physicist, Christiaan Huygens, and the French astronomer Jean Picard published support for Gabriel Mouton's measuring ideas. These ideas were also reported to the Royal Society in London.

The German mathematician, Gottfried Leibniz, published measurement proposals similar to those of John Wilkins and Gabriel Mouton.

1675

Tito Livio Burattini published *Misura Universale* (*Universal measure*) in which he proposed that a pendulum with a period of a second be used as the *universal measure* of length. In his book, Burattini first used the expression '*metro cattolico*' to describe the length of this pendulum. This looks like a direct translation of Wilkins' '*universal measure*' into Italian.

The Italian word '*metro*' derives from '*metron*', a Greek word for measure, and it is probable that the French word, '*mètre*' is also from these sources. Burattini's suggestion led to the name, **mètre**, being used as the base unit of length in France and this subsequently became **metre** in England.

Tito Livio Burattini wrote that the same word for the universal measure should be used:

> *... by all civilized people on earth despite differences in languages and custom.*

The word, *metre*, now serves Burattini's purpose, albeit with slightly different spellings in various languages.

King Charles II established the Royal Greenwich Observatory to determine longitude at sea by 'the astronomical method'. Like the Paris Observatory (1667) its activities were limited to astronomy, navigation, and surveying.

He appointed John Flamsteed as Astronomer Royal. Flamsteed's task was to:

> *... apply himself with the most exact care and diligence to the rectifying of the tables of the motions of the heavens, and the places of the fixed stars, so as to find out the so much desired longitude of places for the perfecting of the art of navigation.*

Rømer published a short paper where he stated for the first time that light has a definite speed. He wrote:

> *This second inequality appears to be due to light taking some time to reach us from the satellite; light seems to take about ten to eleven minutes to cross a distance equal*

Isaac Newton attended his first meeting of the Royal Society in London.

1676

A Danish astronomer, Ole Christensen Rømer (1644/1710), demonstrated that light has a finite speed and he made the first reasonable estimate of the speed of light. Rømer based his estimate on the observations made by Cassini on the movement of Jupiter's moons.

Rømer's value for the speed of light was 220 000 000 metres per second; this is about 25% less than the actual speed of light, that we now know as exactly 299 792 458 metres per second.

Ole Rømer was also a pioneer of the metric system, in that he began to evaluate earth distances by comparing them to the circumference of the whole Earth.

When Ole Rømer visited England in 1679 to examine a pendulum being made at the

Royal Academy, he had meetings with Isaac Newton and Edmund Halley.

1677

Antoni van Leeuwenhoek (1632/1723) saw 'animalcules' (little animals) using his microscope. This was the first view of microorganisms and his observations began the science of microbiology and the need for measurements on an extremely small scale.

1679

John Locke (1632/1704) suggested the word *gry* as a unit for length in a decimal measuring system based on the length of a foot. The gry was to be equal to 0.001 foot and 0.01 inch in a decimalised method for measuring lengths.

Thomas Jefferson (1743/1826), who was very familiar with Locke's writings, proposed a similar system for the USA in 1790 but he changed the name of 0.001 foot to a 'point' rather than a 'gry'. The word 'gry was derived from an ancient Greek word that meant a small amount.

More details of the word gry can be found at:
http://www.onlineunitconversion.com/gry_to_shackle.html

1681

Ole Christensen Rømer became a professor of astronomy in Denmark. One of his first assignments was to reform the Danish weights and measures. He did this by basing all Danish measures on the Rhineland foot.

1682

Sir William Petty (1623/1687) in England put forward a suggestion that there should be five farthings to a penny instead of four so that we could:

> *'keep all accompts in a way of Decimal Arithmetic, which hath been long desired for the ease and convenience of Accompting'.*

1682 December

Isaac Newton made detailed observations of Halley's comet.

1684 December 10

Gottfried Wilhelm von Leibniz published his first publication on calculus, *Nova Methodus pro Maximis et Minimis* (*New Method for the Greatest and the Least*). Although he had developed the calculus from his own entirely independent efforts, it resulted in a bitter priority dispute with Isaac Newton, who had arrived at similar results earlier but had not published them.

1687 July 5

The Royal Society published Sir Isaac Newton's *Philosophiæ Naturalis Principia Mathematica*, Latin for *Mathematical Principles of Natural Philosophy*, that is usually shortened to *Principia Mathematica*. Among many other things Newton's book described the action of gravity on both a human and on an astronomical scale. Newton was aware that a seconds pendulum would have to be shorter near the equator than at the North or South Pole because the force of gravity is greater near the poles and centrifugal forces are greater near the equator. Isaac Newton's book was published with help from the astronomer, Edmond Halley. '*Principia Mathematica*' remains one of the most influential books of all time.

One odd aspect of Isaac Newton's *Principia Mathematica* was that Newton felt he could not rely on English measures for accuracy. Throughout his book he used Parisian feet for all of his measurements.

1689

Charles-Louis de Secondat, baron de La Brède et de Montesquieu (1689/1755), was born in Bordeaux. He was a French social commentator and political thinker who trained as a lawyer, then travelled widely studying political organisations and methods. Montesquieu was highly regarded in the British colonies in America as a champion of liberty. His philosophy was that: *Government should be set up so that no man need be afraid of another.*

Montesquieu was the most frequently quoted authority on government and politics in colonial pre-revolutionary America. Following the Declaration of Independence, Montesquieu's work had a powerful influence on many of the American Founders, especially on Thomas Jefferson, the '*writer of the Declaration of Independence*' and on James Madison, the '*Father of the Constitution*'.

Montesquieu's main work, *De l'Esprit des Lois* (*The Spirit of the Laws*) was published in 1748 and quickly rose to a position of enormous influence. This book became influential as the French Constitution and the Constitution of the USA were being drafted and written.

John Locke published, *A Letter Concerning Toleration* and *Two Treatises of Government*. Locke, an English philosopher, was very influential to the theory of social contract and to the theory of how governments should operate. His ideas had enormous influence on the developments of political philosophy. His writings influenced Diderot, Montesquieu, Voltaire, Rousseau and Thomas Jefferson.

The writings of Rousseau, Locke and Montesquieu all contained ideas that were later used by Thomas Jefferson and the French National Assembly to compose two documents that have had a major effect on the whole world: the American *Declaration of Independence* and the French *Declaration of the Rights of Man and Citizen*.

Both documents provided for standards for weights and measures and for laws and procedures to provide honest measurements for all citizens.

1695

In the lead up to the '*Great Recoinage of 1696'* many voices were heard in support of decimal currency for the UK. For example, an anonymous broadsheet, '*A letter from London to a Friend in Westminster, proposing some Particulars relating in the Coyn*' suggested that a '*William Royal*' should form the tenth part of a pound, a '*Ropee*' should form the hundredth part, and a farthing should be the thousandth part of a pound.

1696

Newton departed Cambridge for London to become Warden of the British Mint.

1699

Newton was elected Foreign Associate of the Académie des sciences (Paris).

Newton was elected to the Council of the Royal Society.

1701

Ole Christensen Rømer made the first practical thermometer. His thermometer used red wine as the temperature indicator. Rømer's temperature scale began at 0 for the temperature of a salt and ice mixture (the coldest thing he could find) and went to 60 for the boiling point of water. On the Rømer scale the freezing point of water was 7½ and human temperature was 22½.

1700

Isaac Newton was appointed Master of the Mint.

1701

Isaac Newton was elected to Parliament as a Senator from Cambridge.

1703

Isaac Newton was elected President of the Royal Society.

1704

In an English Dictionary of Arts and Sciences called *Lexicon Technicum*, the terms 'separating point' and 'separatrix' are used to describe the decimal marker used to separate the whole number part from the decimal number part.

Isaac Newton published the first edition of his book on light and colour called, *Opticks*.

1705

Queen Anne (reigned 1702/1707) knighted Sir Isaac Newton in Cambridge.

1706

The English gallon was standardised as 231 cubic inches (3 785 mL).

Benjamin Franklin (1706/1790) was born in Boston.

1707

The Treaty of Union between England and Scotland extended the weights and measures of England to Scotland. Since then, England and Scotland have had the same standards for weights and measures.

Sir Isaac Newton published *Arithmetica universalis* (*The Universal Arithmetic*) in which he describes decimal methods of calculation.

1713

Jacques Cassini (1677/1756), the son of Giovanni Domenico Cassini, measured the arc of the meridian from Dunquerque to Perpignan. He also observed that all domestic measures in France could usefully be referred to a unit based on a seconds pendulum, and even all European measures, since the length of a seconds pendulum is about the same length throughout the continent of Europe.

Sir Isaac Newton published the second edition of his *Principia Mathematica*.

1714

The Philosophical Transactions of the Royal Society reported on the first account of inoculation against disease in England. This started the fight against smallpox that ended with the global eradication of smallpox by 1979.

1717

Benjamin Franklin invented swim fins for his hands so that he could swim faster.

1718

Benjamin Franklin was apprenticed to his brother James who was a printer.

1720

Sir Isaac Newton's *Universal Arithmetic* was published in an English language edition. There is a copy of this in Thomas Jefferson's Library that is now housed at the Library of Congress in Washington. Jefferson had written a short eulogy to Isaac Newton inside the front cover.

Jacques Cassini proposed the adoption of a geodetic foot representing (1/6000) terrestrial minute of arc.

1724

Benjamin Franklin travelled to London in order to buy printing equipment. Letters of credit for him never arrived so Franklin was stranded in London where he continued to work as a printer's apprentice. While Franklin was in England he swam along the Thames River from Chelsea to Blackfriars; apparently he entertained thousands of onlookers by regularly changing his swimming stroke styles.

Gabriel Fahrenheit (1686– 1736) proposed a temperature scale based on what he considered to be two stable values: the temperature of a mixture of ice water and ammonium chloride at the low end, and the temperature in his wife's armpit at the high end. By a process of continual halving and quartering he arranged for there to be 32 degrees from the low temperature to the freezing pint of water and 64 degrees between the freezing point of water and the temperature of his wife's armpit.

Anders Celsius (1701/1744) used better stable values and decimalised the temperature scale in 1742 (see below).

1726

Sir Isaac Newton published the third edition of Principia.

1727

Although Benjamin Franklin lived and worked in London as an itinerant printer's apprentice, he was still able to meet Sir Hans Sloane (1660/1753), a noted collector of curiosities, who became President of the Royal Society in 1727. Sloane took over the presidency from Sir Isaac Newton. On Sloane's death in 1754, his extensive collections, including much Royal Society-related material, became the core of the British Museum.

Benjamin Franklin returned to Pennsylvania where he developed a talent for printing currency. One employer is quoted as saying he could find '*no one to cut currency like Franklin*'. Franklin helped establish the 'Junto', a society of young men who met for '*self improvement, study, mutual aid, and conviviality*'.

1727 March 20

Isaac Newton died and was buried at Westminster Abbey in London.

1729

Benjamin Franklin wrote a pamphlet, '*The Nature and Necessity of a Paper Currency*'.

1731

Benjamin Franklin drew up the articles of association for '*The Library Company*', the first lending library in America.

1733

Jacques Cassini made measurements of the Earth based on terrestrial minutes of arc. Together with his son, César-François Cassini (1714/1784), they surveyed a portion of the arc of meridian from Dunkerque in France to Barcelona in Spain.

1735

Charles-Marie de La Condamine (1701/1774), and his party measured a geodetic arc of meridian in Peru, where they also made equatorial measurements such as the length of an equatorial pendulum. From these measurements they devised a standard length of a toise (about 1.95 metres) that became known as the *Toise of Peru*. Their work helped to form the basis for the determination of the length of the metre. La Condamine also proposed international cooperation and a pendulum regulated at the equator, as determined by himself and '*the hands of nature*' as the universal standard for length.

1736

Pierre Louis Moreau de Maupertuis (1698/1759) completed a geographical survey in Lapland. This, together with the Cassinis' measurements and the measurements of Charles-Marie de la Condamine in Ecuador and Peru, refined the value of the earth's circumference and radius and established definitively that the shape of the earth is oblate, which means that it's a sort of flattened sphere. Modern measurements show that the diameter of the earth at the equator is 12 756 kilometres and that the diameter through the North and South Poles is 12 715 kilometres. The Earth is 41 kilometres wider than it is tall. Technically the shape of the Earth is called an ellipsoid or a geoid.

The Copley Medal was established from an endowment of £100 received from the estate of Sir Godfrey Copley. It is Britain's oldest scientific honour and a forerunner of the Nobel Prize.

Benjamin Franklin printed the currency for New Jersey.

1737

Pierre Simon Fournier (1712/1768) began to use the point as a typographical unit for measuring printer's type. Fournier published his printing ideas in his book *Manuel Typographique*. As Fournier lived and worked in France his point size was defined as 1/72 of the French Royal Inch of about 27.1 mm (1 Fournier point ~ 376 μm). Later definitions used inches with different lengths; English typesetters used the English inch of about 25.4 mm but kept the 1/72 fraction thus giving English typesetters a point with a different and smaller size. The English point is defined as about 0.013 888 888 … inches (~ 353 μm). Later Nelson C. Hawks (1841/1929) of California redefined the printer's point as 0.138 exactly or 35 μm (see 1868 below).

Benjamin Franklin was appointed Postmaster for Philadelphia in 1737. Later, Benjamin Franklin owned a copy of Pierre Simon Fournier's book *Manuel Typographique*, which he probably purchased directly from Fournier when Franklin was in France as a diplomat between 1776 and 1785.

1740

Nicolas Louis de Lacaille (1713/ 1762) and Jacques Cassini published their results after measuring an arc of meridian in Europe. Their objective was to measure a line extending both sides of latitude 45° along the meridian from Barcelona to Dunkerque. Their plan was to establish the length of a geodetic foot. They intended this foot to be 1/6000 of a terrestrial minute of arc.

Among other achievements, they further refined the value of the earth's radius and established definitively that the shape of the earth is oblate or slightly flattened near the North and South Poles.

These measurements by Lacaille and Cassini formed the basis of the provisional metre established in 1793.

Benjamin Franklin proposed the idea of positive and negative electricity.

1742

For his meteorological observations Anders Celsius constructed his Celsius thermometer, with 0 °C for the boiling point of water and 100 °C for the freezing point. It wasn't until after Celsius' death that the scale was reversed to its present form.

Anders Celsius had previously been part of the French astronomer Maupertuis' famous '*Lapland expedition*' in 1736 to the most northern part of Sweden before he began his work on his temperature scale. The aim of the '*Lapland expedition*' was to measure the length of a degree along a meridian, close to the pole and then to compare the result with a similar expedition to Peru near the equator. These two expeditions confirmed Isaac Newton's belief that the shape of the earth is an ellipsoid flattened at the poles.

The Royal Society in London arranged an exchange of length standards with the Royal Academy of Sciences in Paris. Two identical brass bars were made and a line was marked on them to show the length of the standard yard using the 1720 iron bar of Elizabeth I. This mark was labelled 'E' (for English). When the French scientists received the two bars they marked them with the length of half a toise, labelled it 'F' for France. The French then kept one of these bars and sent the other one back to the Royal Society in London.

In the UK, a new yard became the first imperial standard. It was a standard that had been commissioned by the Royal Society, which in turn had been based on an earlier Elizabethan standard of 1588.

1743 April 13

Thomas Jefferson (1743/1789) was born at Shadwell in Virginia. Coincidentally, this was the 75th anniversary of the publication of Bishop John Wilkins' description of a '*universal measure*' on 1668 April 13.

1743

George Washington (1732/1799) inherited his father's surveying equipment and so was familiar with the simplicity of the decimal measures used with Gunter's decimal chain. This was important because it meant that George Washington had practical daily experience in actual use of a decimal measuring method. That gave him an insight as to how a decimal currency system (such as dollars and cents) might work better than the English pounds, shillings, and pence or the Spanish pieces-of-eight.

Here is an extract from the historical reference at:

http://celebrating200years.noaa.gov/theodolites/theodolitehead_zm.html

> *Several of our nation's early presidents spent time as surveyors. Lawrence and Austin Washington inherited the most valuable of the Washington lands when their father died in 1743, leaving younger brother George Washington (future first president of the United States) in need of a profession. George did inherit Augustine Washington's surveying equipment, and, at age sixteen, George embarked on his first career. George headed across the Blue Ridge Mountains, then considered the western frontier, to survey land for Thomas, Lord Fairfax.*
>
> *Abraham Lincoln wrote of the time he spent as assistant to the Sangamon County (Illinois) Surveyor as something that 'procured bread and kept soul and body together'. Unfortunately, it apparently didn't always pay the bills, as in 1834 Lincoln sold his surveying equipment at auction to pay a debt.*

1744

Swedish naturalist, Carl Linnaeus (1707/1778) suggested reversing the temperature scale of Anders Celsius so that 0 degrees represented the freezing point of water (273.15 K) and 100 degrees the boiling point (373.15 K). This became known as the centigrade temperature scale and gradually became popular throughout the world. The units of the centigrade temperature scale were designated 'degree centigrade' (symbol – °C).

The 9th Conférence Générale des Poids et Mesures (CGPM) and the Comité International des Poids et Mesures (CIPM) in 1948 formally changed the name 'degree centigrade' to 'degree Celsius', and kept the same symbol – °C.

1745

In England, Bishop Fleetwood, concerned about uniformity of measures, wrote:

> *What can be more vexatious and unprofitable, both to men of reading and practice, than to find that when they go out of one country into another, they must learn a new language or cannot buy or sell anything. An acre is not an acre; nor a bushel a bushel if you but travel ten miles. A pound is not a pound if you go from a goldsmith*

to a grocer, nor a gallon a gallon if you go from the alehouse to the tavern. What purpose does this variety serve?

Benjamin Franklin learned about the newly invented Leyden jar (an early type of capacitor invented in the Netherlands) from correspondence with Peter Collinson FRS, a London merchant. He made his own Leyden jar and wrote an explanation of how the capacitor stored electricity. Franklin's explanation included the ideas of positive and negative charge and the concept of conservation of charge. These ideas influenced the next generation of European electrical experimenters, such as Alessandro Volta (1745/1827)

1747

Charles-Marie de La Condamine repeated Wilkins' proposal for a '*universal measure*' when he wrote '*Nouveau projet 00d'une mesure invariable, propre à servir de mesure commune à toutes les nations*' (*New project for an invariable measure appropriate to serve community measures for all nations*). Writing about the need for common measures, he said:

It is quite evident that the diversity of weights and measures of different countries, and frequently in the same province, are a source of embarrassment in commerce, in the study of physics, in history, and even in politics itself; the unknown names of foreign measures, the laziness or difficulty in relating them to our own give rise to confusion in our ideas and leave us in ignorance of facts which could be useful to us. The variety of measures in different countries, and even in the same country, is an embarrassment. It makes life difficult in trade, banking, science, history, and even in politics.

In France the infinite perplexity of the measures exceeds all comprehension. They differ not only in every province, but in every district and almost every town. A pinte of wine in Saint-Denis was one-third larger than a pinte in Paris. A carpenter's pied (foot) was not the same as the ironmonger's foot. There were about 700 names of measures and 250 000 different units of measurement.

Condamine proposed that the length of the equatorial seconds pendulum should be adopted as a universal standard. He had a brass rod made to this length, sealed it in a block of marble, and had it inscribed: *A natural unit – may it become universal.*

Jean-Baptiste Joseph Delambre (1749/1822) was born.

1748

Baron de Montesquieu published *De l'Esprit des Lois* (*The Spirit of the Laws*) in which he emphasised the need to curb arbitrary government by separation and balance of powers. Montesquieu's ideas were later embodied in the constitution of the USA and in the constitution of France.

Benjamin Franklin carried out experiments on lightning.

1751

The new year in the UK began on 1 January rather than 25 March to bring it into line with the rest of Europe because England and the British Dominions began to use the Gregorian calendar (new style) rather than the Julian calendar (old style). Part of the reason given for this change was the difficulty of calculating interest of loans. They wrote:

... attended with divers inconveniences, not only as it differs from the usage of neighbouring nations, but also from the legal method of computation in Scotland, and from the common usage throughout the whole kingdom, and thereby frequent mistakes are occasioned in the dates of deeds and other writings, and disputes arise therefrom ...

Benjamin Franklin wrote to a friend in London, Peter Collinson, about how he nearly electrocuted himself while conducting electrical experiments on turkeys. Collinson published Benjamin Franklin's letters on electricity in London.

After 20 years of research, writing and editing, Denis Diderot (1713/1784) published the first volume of his *Encyclopédie*. Diderot had arranged articles by nearly all the leading French writers of the time in alphabetical order and then cross-referenced them to make finding information easier. The articles covered many questions of philosophy, religion, literature, politics and science. Because of the opposition of the Catholic Church to public discussion of many of these topics, Diderot was at constant risk of imprisonment or exile. The *Encyclopédie* was seen as a statement and development of the ideas of the *philosophes* of the *Enlightenment*. The *Encyclopédie* had a great influence on thinkers in the latter part of the 16^{th} century.

1752

England and its American colonies adopted the Gregorian calendar by removing 11 days from the year. This was 170 years after the initial adoption of the Gregorian calendar in most of Europe. There were people dissatisfied with this decision and a Hogarth painting (of 1755) shows a placard that reads *Give us our Eleven Days*.

Benjamin Franklin ran a wet string from a kite to extract electric charge from a storm cloud. He pressed his knuckle to a key on the string to feel an electric spark and then he charged a Leyden jar at the end of the string. The image of Franklin and his kite is one of the most familiar in science and it made Benjamin Franklin internationally famous, especially when his report describing the experiment was published in the Royal Society's *Philosophical Transactions* in London.

1753

The Calendar Act (also known as Chesterfield's Act) in the UK made provision to make sure that monthly or yearly payments would not become due until the dates that they originally would have in the Julian calendar. For this reason the UK tax year continued to operate on the Julian calendar and began on 5 April, which was the old style date for the new style tax year that began on March 25.

Benjamin Franklin was awarded the Royal Society's Copley Medal. His written comments on receiving this award are still remembered. He wrote:

> *I know not whether any of your learned Body have attain'd the ancient boasted art of multiplying Gold, but you have certainly found the Art of making it infinitely more valuable.*

In both America and England there were religious objections to Franklin's lightning rods as circumventing divine wrath. However the continuing death rate of church bell ringers eventually proved Franklin's case!

Benjamin Franklin received honorary degrees from Harvard and Yale and was appointed joint Deputy Postmaster General for North America.

1755

Two brothers, Francois Ambroise Didot and Pierre Francois Didot, modified and developed Fournier's points for measuring printing type.

1756

Benjamin Franklin was elected as a Fellow of the Royal Society of London even though he was a resident of Philadelphia.

Edmund Burke (1729/97) published (anonymously) *A Vindication of Natural Society*.

1757

From 1757 to 1762 Benjamin Franklin (1706/1790) was in England as agent for Georgia, Massachusetts, New Jersey, and the Pennsylvania Assembly.

Thomas Jefferson inherited his father's (Peter Jefferson) surveying equipment, again with a decimal Gunter's chain, See **http://wiki.monticello.org/mediawiki/index.php/Surveying.**

This was important because it meant that Thomas Jefferson had practical daily experience in actual use of a decimal measuring method that gave him insight into how a complete system of measurement might work for the USA. And like George Washington, it also gave him insight into how a decimal currency system (such as dollars and cents) might work better than the English pounds, shillings, and pence, or the Spanish pieces-of-eight.

Here is another extract from the historical reference at **http://celebrating200years.noaa.gov/theodolites/theodolitehead_zm.html**

> *While it may not be common knowledge that Presidents Washington and Lincoln were practitioners of the science of surveying, it should come as no surprise that Thomas Jefferson, the same President who referred to freedom as 'the first born daughter of science', sent the Lewis and Clark Expedition west and established the Survey of the Coast, was also fascinated by the mathematics and techniques of surveying. Although he filled the post of Albemarle County (Virginia) Surveyor for a short time, Jefferson primarily used his skills on his own lands. However, in 1815, at the age of 72, Jefferson used the theodolite to determine the elevation of the Peaks of Otter in the Blue Ridge Mountains.*

This fascinating piece of information provided me with the missing link as to how the system of '*universal measure*' travelled from England in 1668 to France in the 1790s. It seemed to me that the idea for a decimally based '*universal measure*' travelled from England to France in large part via the USA through two people, George Washington and Thomas Jefferson, as both of these men had had direct experience with the simplicity of decimal numbers in their surveying calculations using Gunter's chain.

Benjamin Franklin went to London as a colonial agent for the Pennsylvania Assembly. Franklin's duties were light so he had time to travel widely and to popularise his scientific interests to non-specialists.

1758

The English Parliament ordered the construction of another new '*standard yard*' and another new '*standard pound*' to be kept in the Houses of Parliament in London. John Bird (1709/1776), an astronomical instrument maker who worked in The Strand in London, made the standard yard for the government. He made another one for them in 1760. These were the two standard yards that were destroyed when the Houses of Parliament burned down in 1834. The standard pound was made by Harris.

1759

Benjamin Franklin received an honorary degree of Doctor of Laws from the University of St. Andrews, Scotland.

Voltaire published his novella *Candide, ou l'Optimisme* (*Candide or The Optimism*). The story begins with the sheltered life of a young man, Candide, who is being taught by his tutor, Pangloss, that '*all is for the best in the best of all possible worlds'*. Candide's paradisiacal life ends, and then Candide has to face the realities of the hardships that exist in the real world.

Voltaire was the pen name of François-Marie Arouet (1694/1778). He was a French Enlightenment writer and philosopher known for his wit, philosophy, and for his defence of civil liberties such as freedom of speech, freedom of religion, and free trade. Voltaire often used his talents to criticize French customs especially the dogma and practices of the Catholic Church, despite the strict censorship laws and their harsh penalties at the time. Even though he had been imprisoned in the Bastille, the large prison in Paris, Voltaire continued to be an unsparing critic of existing institutions, and in particular the Catholic Church.

Voltaire was one of the Enlightenment figures whose writings influenced important thinkers of both the American and French Revolutions.

1760

Benjamin Franklin was elected to the Council of the Royal Society.

John Bird made another standard yard at the request of a Parliamentary committee. Both of Bird's yards were made of brass and contained a gold button near each end. A dot was engraved in each of these two buttons, with the two dots spaced 1 yard apart.

This second yard was not legally recognised as a standard yard until 1824 May 1, when an act establishing imperial measure declared that the yard Bird made in 1760 would be the prototype of the imperial yard, and that all length measures were to be based on it.

In 1834, less than ten years later, the UK Houses of Parliament burned down and both of Bird's yards – the 1758 and the 1760 – were destroyed.

1761

Benjamin Franklin perfected his glass harmonica, a musical instrument that used the idea of a wet finger rubbed around the rim of a wine glass to produce sounds. Both Mozart and Beethoven wrote pieces for Franklin's invention.

At this time Franklin supported the work of Joseph Priestley (1733/1804), who used electricity to dissociate gases and later discovered oxygen and the use of carbon dioxide in carbonated beverages. Later Joseph Priestly went to the new American Republic to join Franklin in Pennsylvania.

John Harrison (1693/1776), an English clockmaker and carpenter, invented his first highly accurate clock, called a chronometer, to determine longitude at sea.

1762

Jean Jacques Rousseau (1712/1778) published *Du Contrat Social* (*Of Social Contracts*) in which he argued that man is: *born free, (but) is everywhere in chains*.

Rousseau argued strongly that the ideas and desires of the people should be what is actually carried out by governments. In short, he argued for democratic governments where a large state was split into a number of small direct democracies that were bound together into a federation. Rousseau's ideas about the nature of democracy were developed later by revolutionary leaders in France and the USA.

1766

During Benjamin Franklin's second London visit he petitioned King George III (reigned 1760/1820) for the establishment of central British government for Pennsylvania. He became friendly with the King's physician, Sir John Pringle, who was also President of the Royal Society. The two became close companions and they travelled together to Germany (in 1766) and to pre-Revolutionary France (in 1767) where they met King Louis XV (reigned 1715/1774) at his palace in Versailles.

The Congress of the USA appointed Benjamin Franklin to France as its first ambassador. He served in France as one of the Commissioners of Congress to the French Court from 1776 to 1784.

Joseph Priestley developed the *inverse square law* for the force between electric charges.

1766

King Louis XV of France ordered the construction of 80 new standard *toises* to be based on the geographically surveyed *toise of Peru.*

1768

The Royal Society sent James Cook (1728/1779), on the ship *Endeavour*, to Tahiti where he was to observe the transit of Venus across the face of the Sun. Astronomers had calculated that this would happen in 1769. On his return trip Cook visited the places we now know as Australia and New Zealand.

James Cook had two chronometers with him on this voyage. A chronometer is essentially a clock with a built-in temperature adjustment for greater accuracy. An accurate chronometer allows a navigator to determine where they are on the globe of the Earth. Cook's chronometers were a little over 16 kilograms and although they were precise, they were not accurate. This didn't matter as the indicated time could be adjusted with tables supplied with each clock. I recall a poem by Kenneth Slessor (1901/1971), written in 1925, that described Cook's two chronometers. In part it went:

Two chronometers the captain had,
One by Arnold that ran like mad,
One by Kendal in a walnut case,
Poor devoted creature with a hangdog face.

Arnold always hurried with a crazed click-click
Dancing over Greenwich like a lunatic,
Kendal panted faithfully his watch-dog beat,
Climbing out of Yesterday with sticky little feet.

1769

James Watt (1736/1819) patented the steam engine.

1769 June 3

Captain James Cook observed the transit of Venus. He wrote in his log:

> *This day prov'd as favourable to our purpose as we could wish, not a Clowd was to be seen ... and the Air was perfectly clear, so that we had every advantage we could desire in Observing the whole of the passage of the Planet Venus over the Suns disk: we very distinctly saw an Atmosphere or dusky shade round the body of the Planet which very much disturbed the times of the contacts particularly the two internal ones.*

David Rittenhouse (1732/1796), an American astronomer, instrument maker and inventor also made detailed observations of the transit of Venus using devices that he had invented or built. These included a high precision pendulum clock, an astronomical quadrant, an equal altitude instrument, and an astronomical transit. Rittenhouse was professor of astronomy at the University of Pennsylvania and a consultant to Benjamin Franklin and to Thomas Jefferson. He advised the latter on the project to establish a decimal system of weights and measures for the USA.

1769 August 15

Napoleon Bonaparte was born at Ajaccio, in Corsic on August 15. Napoleon was the fourth child of Charles Bonaparte and of Lititia, *née* Ramolino.

1769-75

Thomas Jefferson became a Member of Virginia House of Burgesses where he helped to set up the Virginia Committee of Correspondence.

1770

Benjamin Franklin charted the Gulf Stream. He also proposed the idea of watertight compartments to prevent ships sinking and investigated the way in which oil could be used to calm water surfaces.

The UK passed the False Weights and Scales Act

1771

The 1771 edition of the Encyclopaedia Britannica says: '*The point thus prefixed is called the decimal point*' in its article on '*Arithmetick*'.

1773

Jesse Ramsden (1735/1800) invented the circular-dividing engine. Early models of this machine were able to divide circles to a repeatable accuracy of three seconds of arc; later models reduced this to one second of arc.

This meant that all of his surveying and astronomical instruments could be made much more accurately and precisely. Ramsden soon gained a high reputation for the high quality instruments he produced. These included high quality physics apparatus but also included eyeglasses and large astronomical telescopes. The leading scientists of his time recognized Ramsden's work by making him a Fellow of the Royal Society in 1786.

1774

Gilbert White (1720/1793) and the Royal Society published his letters on ornithology, the study of birds. Later (in 1784), his systematic records were published in *The Natural History of Selborn*e; it became one of the most popular nature books of all time.

1775

Marie-Jean-Antoine-Nicolas Caritat, marquis de Condorcet (1743/1794), usually just called Condorcet, wrote about having an invariable standard measure that was based on a natural standard taken from nature. Condorcet hoped that that this would lead to a standard that would not be based on any national vanity, that could be used by all foreign nations, and that would be used for all international trade between all nations.

Benjamin Franklin left London, and shortly thereafter presided over the constitutional convention, serving on a committee of five who drafted the Declaration of Independence, that declared the independence of a new nation, the United States of America.

The constitution writers recognised the importance of a uniform system of weights and measures for the whole of the USA, so in Article I, Section 8, of the constitution they wrote that Congress would have the power *to coin money ... and fix the standard of weights and measures.*

Benjamin Franklin was elected as the Pennsylvania delegate to the second Continental Congress that expelled royal officials and formed an army. Franklin also served as Chairman of Pennsylvania Committee of Safety and he was elected Postmaster General for the Colonies.

André-Marie Ampère (1775/1836) was born in Lyon, France. The SI unit of measurement of electric current, the ampere, is named after him. Although he was a French physicist and mathematician, he was awarded a Fellowship of the Royal Society (FRS) of London because he was generally regarded as the main discoverer of electromagnetism.

Captain Cook returned from his second voyage (1772– 75), The English Parliament had offered a reward to anyone who could find a way to accurately determine longitude. John Harrison, a self-educated English carpenter and clockmaker, designed a number of marine chronometers, and a copy of his fourth one went with Cook on his second voyage and enabled him to calculate his longitudinal position with great accuracy. This gave England a huge advantage over other nations; this single invention led to the ascendancy of the Royal Navy, and thus to the reach of the British Empire. Accurate and precise measurement can have far-reaching effects.

1775 April 18

Paul Revere's midnight ride to warn colonists that '*the British are coming'*. Paul Revere (1735/1818) was a silversmith, part-time dentist, and a highly regarded patriot.

1775-76

Thomas Jefferson attended the Continental Congress. He was chosen to be on the committee to write the Declaration of Independence and quickly became its main author.

1776

Benjamin Franklin returned to Europe as one of the Commissioners of Congress to the French Court to represent the new United States of America in Paris. He carefully cultivated an image as a fur cap-wearing frontiersman seeking freedom from an oppressive government, which endeared him to the French, and greatly increased his effectiveness as an agent of the USA.

Lieutenant General Jean-Baptiste Vaquette de Gribeauval (1715/1789) developed new methods for producing military cannons. Gribeauval is usually given the credit for engineering in a way that allowed for the interchangeability of gun parts. Cannons produced using Gribeauval's new manufacturing system proved essential to French military victories during the Napoleonic wars.

Gribeauval's concept of uniformity and interchangeability of parts was soon promoted in the USA by Thomas Jefferson, who could see the benefits that these properties could make to guns made in the USA. To achieve uniformity and interchangeability it was necessary to measure more accurately and more precisely than had ever been done before. There also needed to be advances in precision in machine tools and their application. In the USA Thomas Jefferson was a natural champion for these advancements, so gun-makers in the USA were soon able to accomplish remarkable results using Gribeauval's methods.

1776-79

Thomas Jefferson became a Member of the Virginia House of Delegates, where he was involved in rewriting state legal documents to reflect republican principles concerning landholding, inheritance and criminal law.

1777

Condorcet became secretary of the French Academy of Science and held this position until his death in 1793.

1778

Jacques Necker, the Controller General of Finance in France, reported to Louis XVI that he had examined the means that might be employed to render the weights and measures uniform throughout the French kingdom, but doubted whether the result would be proportionate to the difficulties involved.

Benjamin Franklin signed the '*French Alliance*' between France and the United States of America, but Franklin's primary objective, of raising funds for a war against Britain as an enemy nation, did not prevent him from promoting the cause of science. For example, Franklin wrote a 'passport' for Captain James Cook FRS, who was then on his third voyage of discovery in the Pacific on a ship called *The Resolution*. Franklin urged the captains of any armed ships acting for the United States of America to regard Cook and his crew as *... common Friends to Mankind ... and ... to treat the said Captain Cook and his People with all Civility and Kindness*.

Benjamin Franklin also maintained cordial links with Sir Joseph Banks (1743/1820), John Pringle's successor as President of the Royal Society. Franklin sent news of the latest in French science to Joseph Banks and John Pringle. John Pringle probably lost the presidency of the Royal Society largely because he backed Franklin's idea that pointed lightning rods were more effective than rounded ones.

Franklin perfected bifocal spectacles in Paris and these became one of his most famous inventions.

1778

France played an important part in the victory of the USA over Britain by providing military help to the USA on both land and sea. Official support of the USA by France came with a formal treaty of friendship and alliance signed on February 6 by Louis XVI, King of France, and Benjamin Franklin, Ambassador to France from the USA. Many young French aristocrats passionately embraced the rebellion of the 13 American colonies against British rule.

Napoleon embarked for France with his father, his brother Joseph, and his uncle Fesch.

1779

Benjamin Franklin was appointed to negotiate a peace treaty with England.

1779-81

Thomas Jefferson was Governor of Virginia.

1781

French involvement in the American war of Independence proved decisive, with a French naval victory in the Chesapeake leading to the surrender of a British army at Yorktown.

1781

Joseph II and Ferdinand signed a decree in Vienna that laid down a reform program to standardise measures of length where the '*ell of Milan*' was to become the standard length. This reform was restricted to the state of Milan, but their justification for this reform could have been used in any European country at that time; they said:

> *The dimensions and diversity of the measures in use in different regions of our state, although it has one law and obeys one ruler, and the absence or inexactitude of the standards employed by the agencies of control – these are matters that have always been considered as sources of errors … and a hindrance to the flow of secure internal and foreign trade.*

Friedrich Wilhelm (William) Herschel (1738/1822), an orchestral musician (oboe and cello), organist and composer, discovered the planet Uranus.

In his musical and astronomical work, Herschel was assisted by his sister Caroline Lucretia Herschel (1750/1848). Caroline was a gifted soprano and astronomer who later discovered eight comets.

1782

Jean-Charles de Borda (1733/1799) was a French mathematician and nautical astronomer who developed instruments for navigation and for geodesy (the study of the size and shape of the Earth).

He developed a series of trigonometric tables for his studies in astronomy, calculus, fluid mechanics, geodesy, navigation, physics, surveying, and for the further development of his scientific instruments.

He was in command of a flotilla of six French ships while supporting the American War of Independence when captured by the British. Later he was one of the main driving forces in the introduction of the decimal metric system as the legal measures of France.

In the USA, Thomas Jefferson argued for a decimal currency system with 100 cents in a dollar. Jefferson reasoned that dividing America's First Silver Dollar into 100 cents was the simplest way of doing this and that a decimal system based on America's First Silver Dollar should be adopted as the American standard. His plan went like this:

10 mills = 1 cent, 10 cents = 1 dim, 10 dimes = 1 dollar, 10 dollars = 1 eagle

The mill was a denomination used only in computations – it was never intended to be a coin; as a prefix for the metric system it appeared again a few years later as *milli*.

1783

Benjamin Franklin signed the Peace Treaty between the Kingdom of England and the United States of America. The Treaty of Paris in 1783 formally ended the war and recognized the sovereignty of the United States over the territory bounded by (what is now) Canada, Florida, and the Mississippi River.

Franklin was present to witness the first hot air balloon demonstrations by the Montgolfier brothers. Franklin favoured the hydrogen method and helped to finance balloon tests, sending word of the first manned flight back to Joseph Banks in England shortly after the Montgolfiers' successful flight experiments.

Jean Dominique Cassini, the Director of the Paris Observatory, suggested the observatory in Paris and the Greenwich observatory be carefully surveyed, so that observations made at either place could be compared. This could be resolved by triangulating the south-east of England and extending the measurement across the channel to France. The President of the Royal Society, Joseph Banks, supported this suggestion and appointed Major General William Roy (1726/1790) to do the work. To begin, Roy commissioned Jesse Ramsden, a very well respected scientific instrument maker, to make him a number of new instruments to do this work.

1784

Using Jesse Ramsden's new instruments, William Roy measured a base line with deal rods and iron bars as 27,404 feet. He re-measured the same line with 1370 placements of glass rods and the length was then given as 27 406 ft. After allowing corrections for temperature, and correcting for mean sea-level, the value was determined to be 27,404.2 ft. We would now take this to be 8352.800 metres or 8.352800 kilometres.

In September 1784 Jean Dominique Cassini, Comte de Thury, wrote to Charles Blagden, the recently elected Secretary of the Royal Society, asking Blagden to support him to become a member of the Royal Society, to carry on his father’s work there. His father had been elected in 1750; the Comte de Thury was elected in 1789.

1784-89

Thomas Jefferson served in France as Commissioner and Minister to the French Court.

1785

Charles-Augustin de Coulomb (1736/1806) presented his three reports on Electricity and Magnetism. In these Coulomb defined the electrostatic force of attraction and repulsion that became known as Coulomb's law. The SI unit of charge, the coulomb, was named after him.

After the war the several states of the USA had to honour the grants of land they had made to the officers and men of the Revolutionary army. They also had to repay the debts they owed to foreign governments, especially to France. By 1785 most of the states had decided to pass the authority for doing this to the federal government, so Congress passed its first ordinance, describing the method to be used for surveying and cutting up its new lands for disposal to soldiers, creditors, and settlers.

In *The Measure of Enlightenment*, J.L. Heilbron describes the process like this:

The ordinance represented a great victory for the quantifiers, led by Thomas Jefferson, who insisted that the lands be surveyed into equal spans before being offered, and subdivided into parts affordable by small farmers; their opponents, primarily southern aristocrats and plantation owners, favoured large grants to companies or wealthy individuals who would undertake to divide it up into such shapes and by such boundaries as suited their interests …

Jefferson's original proposal would have divided the western territories into what he called 'hundreds' – squares with sides of 10 nautical miles – rather than the townships of 36 square statute miles Congress eventually authorized. Each hundred was to contain 1,000 Jeffersonian acres and so on, for Jefferson, who invented the American system of pennies, dimes, and dollars, championed decimal division almost as strongly as democracy. He and the professor of mathematics who helped him work out his system of rigid squares recommended it for its order and clarity, and as an obstacle to cheating. They argued that irregular lots inspired fraud, and could point to the experience of Massachusetts, which discovered that holdings in the country typically held 10 percent more land, and often 100 percent more land, than had been granted. Friendly surveyors set the boundaries where their clients wished. The square grid made the practice much more difficult and allowed purchasers to get more or less what they paid for.

Despite his comments, Jefferson's arguments did not prevail and Federal legislation in the USA required that official surveys were to be done using Gunter's chains made up of 100 links each 7.92 inches long. This was in recognition of the fact that Gunter's chain had already been widely used for many years throughout the USA.

The Pavillon de Breteuil was given its present name when it became associated with the most distinguished member of the Breteuil family, Louis-Auguste le Tonnelier, Baron de Breteuil (1730/1807). Baron de Breteuil had a distinguished career in the diplomatic service of the King of France. At one time he was ambassador to Russia during the reigns of Elizabeth and Catherine II. After many successful international negotiations, the Baron returned to France in 1783 and was made Minister of the King's Household, and Minister for Paris.

The Baron de Breteuil was a man whose humanitarian and social views were far in advance of his time. During his period as Minister for Paris, he introduced far-reaching reforms in hospitals and prisons. He also took a great interest in the world of science and became a member of the French Academy of Sciences.

1785

James Madison (1751/1836) wrote to James Monroe (1758/1831) to express his concerns about currency, weights, and measures. It would appear that James Madison, who would be the 4th President of the USA, had been influenced by Thomas Jefferson's decimal ideas on currency, weights, and measures (Jefferson would be the 3rd President of the USA) and was passing on these ideas to James Monroe, who would be 5th President of the USA.

I hear frequent complaints of the disorders of our coin, and the want of uniformity in the denominations of the States. Do not Congress think of a remedy for these evils? The regulation of weights and measure seem also to call for their attention. Every day will add to the difficulty of executing these works. If a mint be not established and a recoinage effected while the federal debts carry the money through the hands of Congress, I question much whether their limited powers will ever be able to render this branch of their prerogative effectual. With regard to the regulation of weights and measures, would it not be highly expedient, as well as honourable to the federal administration, to pursue the hint which has been suggested by ingenious and philosophical men, to wit: that the standard of measure should be first fixed by the length of a pendulum vibrating seconds at the Equator or any given latitude; and that the standard of weights should be a cubical piece of gold, or other homogeneous *body, of dimensions fixed by the standard of measure ? Such a scheme appears to be easily reducible to practice; and as it is founded on the division of time, which is the same at all times and in all places, and proceeds on other data which are equally so, it would not only secure a perpetual uniformity throughout the United States, but might lead to universal standards in these matters among nations. Next to the inconvenience of speaking different languages, is that of using different and arbitrary weights and measures.*

1784-1789

In the late 1780s, French weights and measures were a mess. There were hundreds of units, many of which had hundreds of local values. At the same time the French economy was industrialising, but its measuring methods could not support these developments.

Long before the revolution, French people from all walks of life were calling for measurement reforms and there was a feeling that measurements should, somehow or other, be '*natural*', rather than being based on the hated '*royal foot*'.

Charles Maurice de Talleyrand-Périgord (1754/1838), Bishop of Autun in France and usually known simply as Talleyrand, Sir John Riggs Miller (1744/1798) in England and Thomas Jefferson, USA Minister to France from 1784 to 1789, corresponded on a proposal for universal measures. It seems most likely that Jefferson promoted his strong support for decimal measurement and decimal currency at this time.

Essentially, Talleyrand, Riggs Miller, and Jefferson were proposing that their three nations should cooperate to equalise their weights and measures, by the joint introduction of a 'decimal système metrique' (decimal metric system).

The decimal nature of the new *decimal metric system* probably arose from the influence of three men: Benjamin Franklin, Thomas Jefferson and George Washington. They provided the missing link as to how the system of '*universal measure*', now known as the metric system or SI, travelled from England in 1668 to France in the 1790s. It would appear that it travelled in large part through the USA via two people, George Washington and Thomas Jefferson, who had both had direct experience with the ease of use of decimal numbers in their surveying calculations using Gunter's chain, and Benjamin Franklin who was a promoter of decimal currency.

1786

Thomas Jefferson proposed that the USA adopt a decimal system for their currency. The Congress of the USA established the silver dollar as the basis for decimal coins, although this was not minted until 1792.

At the same time Thomas Jefferson independently developed a system of decimal measures for all measuring. Jefferson's decimal measures heavily influenced the development of the French *decimal metric system* that arose in the 1790s. He differed from the French in that he wanted the metre to be the length of a pendulum that beats seconds, because other countries could readily reconstitute that at any time. He did not like the idea that the metre be based on a series of measurements made within the French nation. However, considering how much gravitational forces (together with centrifugal forces) vary over the surface of the earth with latitude – more than 1% – the pendulum definition for the universal measure of length was losing widespread support among scientists.

On 1786 March 12 Thomas Jefferson made his only visit to London, then the largest city in the western world, and was there until 1786 April 26.

1787

The Congress of the USA asked Benjamin Franklin to design a one-cent coin, as there was a shortage of small coins at the time. Franklin's design for the first one-cent coin for the USA later became known as the '*Fugio*' cent because on one side of the coin he placed the word *Fugio* next to a sundial, together with one of his favourite mottoes, *Mind Your Business*. He intended this to imply that *Time Flies* so *Mind Your Business*. On the other side of the coin Franklin had thirteen entwined rings, one for each of the thirteen states, and in the centre the words *We are one*. Franklin's Fugio Cents were minted and entered circulation immediately.

On September 17, the United States of America adopted the Constitution as the supreme law of the United States of America. It took effect in 1789.

Article I, Section 8, of the Constitution provides that Congress shall have the power: *to coin money ... and fix the standard of weights and measures*.

Another provision of the Constitution stated that '*all duties, imposts and excises shall be uniform throughout the United States of America*'. Benjamin Franklin was one of the signatories of the United States Constitution.

To avert a bankruptcy, King Louis XVI (reigned 1774/1792) convened the Estates General, which had not met since 1614, for the purpose of imposing new taxes.

The Estates General consisted of the three French estates; the first estate was the clergy, the second estate was the nobility and the third estate was the bourgeoisie, the urban workers and the peasants.

One of the issues for discussion was that of fair and honest measurement. There had been many previous attempts to impose the '*Parisian*' units on the whole of France, but they were opposed by the church, the guilds, and the nobles, who benefited greatly from measurement confusion.

Baron de Breteuil resigned from the King's service.

1787

Cross-channel measurements were taken linking France and England. While this work was proceeding, triangulation survey work continued further inside England, forming the basis of the Ordnance Survey. This was the final part of the process to connect the observatory in Paris and the Greenwich observatory so that they could accurately share data with each other.

The Constitution of the USA was created, giving the Congress of the USA the power to ... *fix the standard of weights and measures*.

1788

In Paris, there were methods of producing portraits that would certainly have appealed to anyone with scientific curiosity. In one Paris studio customers sat for silhouette portraits using a device called a psysiognotrace. Both Thomas Jefferson and Benjamin Franklin were customers for these portraits. Another one of these had a complicated device that enabled the inventor to produce exact three-dimensional models of their subjects. Again, American Ambassadors Franklin and Jefferson were customers.

Just before the Revolution, Gaspar de Prony declared the pendulum to be the ultimate standard for length. He wrote that the standard length should be:

> *... the length of the simple pendulum, an invariable quantity always easy to recover, seemed given by nature to serve as a measure in all countries.*

At this time, Sir John Riggs Miller was about to introduce proposals for the reform of English weights and measures when he received a letter from Talleyrand, inviting Britain to join France in finding the length of a seconds pendulum. The British considered the advantages of this suggestion, and of calibrating their yard by the pendulum, so that:

> *... all future generations may obtain similar measures of length, capacity, and weight, and thereby render it altogether needless to cut them on stone, or to engrave them on brass to perpetuate their existence.*

1788 June 21

The Constitution of the USA was ratified.

1789

Sir John Riggs Miller raised the question of honesty in weights and measures in the UK House of Commons and shared his thoughts on rational methods to improve weights and measures. He also pointed out the difficulties arising from the use of multiple measures in the UK where he was quoted as saying that disorganised measures led to

> ... *the perplexing of all dealings, and the benefitting of knaves and cheats*

The First Congress of the USA took up the question of weights and measures, and had the metric system been available at that time it might have been adopted. What actually happened is that Thomas Jefferson, who was then serving as the first Secretary of State, submitted a report proposing a decimal-based system with a mixture of familiar and unfamiliar names for the units. No doubt Thomas Jefferson passed copies of this report to his friends in Paris, such as Talleyrand and Condorcet, and to John Riggs Miller in the UK, as he knew they were also working on the reform of weights and measures. It is likely that they were as impressed by his report as they were with his success at promoting a decimal currency for the USA.

1789 March/April

King Louis XVI ordered that a list of grievances (*cahiers de doléances*) be written. These grievances were then to be considered by the Estates General. The Estates General consisted of the three French estates; the first estate was the clergy, the second estate was the nobility and the third estate was the bourgeoisie, the urban workers and the peasants.

Measuring issues were a constant theme in these lists of grievances, especially about how they related to rents, tithes and taxes. Delegates from many French towns petitioned King Louis XVI to unify the measuring methods in France so that they were fair to all.

Here are some examples from the *cahiers de doléances* (*list of grievances*):

> *Are the seigneurs not obliged to present to us some documents in support of the size of the measures they employ?*
>
> *In cases where the seigneurs' measures are found to be in excess of what they should be, are they not obliged to restore to their rent payers the resultant excess amounts? Over how many years, retrospectively, may the payers demand such 'restitutions'; does the usual time-limit applicable to private prosecutions, thirty years, hold here, or should the measuring abuses be deemed criminal fraud and be subject to no rule of lapse at all?*
>
> *The seigneurs avail themselves of the crafty dealings of their underlings, who recover from the tenants the large amount they had themselves been forced to invest, as the price of their position.*
>
> *The grain measures must now be heaped not striked as they were in the past.*
>
> *The seigneur's agents are employing two different measures: one of them is larger than the proper one and is used in the collection at the granary. The payers are not blind to this injustice, but are too afraid to protest.*
>
> *The seigneurs and their agents use falsified and oversized measures.*
>
> *The seigneurs have been gradually increasing their boisseaux (bushels), until, in effect, the payments of dues they exacted are quite arbitrary.*
>
> *There are almost as many local measures to collect dues, as there are estates.*
>
> *What is the use to us of the abolition of the feudal system, if the seigneurs remain at liberty arbitrarily to increase or decrease their measures?*

> *What is to be done in instances when, the seigneur having failed to produce documents in support of his right to use the measure he has adopted, a proper agreed-upon measure has to be determined?*

No doubt the king hoped to relieve tensions by giving the people of France the chance to express their hopes and grievances directly to the king. However, the writing of the *cahiers de doléances* forced the people to think about the problems that France faced, and about how they wanted them fixed, so they added greatly to an air of revolutionary expectation in France.

1789 May 5

The French Estates General, which consisted of the three French Estates (the church, the nobles, and the commoners) convened at the Palace of Versailles.

1789 June 17

The Third Estate, consisting of the middle class bourgeoisie, the urban workers and the peasants, proclaimed itself to be the National Assembly of France. This decision left out members of first estate, the church, and the second estate, the nobles.

1789 June 27

The French Academy of Science named Commissioners to work with the drafting of a plan for the uniformity of weights and measures in France. The commissioners were: Jean Charles de Borda, Joseph-Louis Comte de Lagrange (1736/1813), Pierre-Simon Laplace (1749/1827), Gaspard Monge (1746/1818), and Marie Jean Antoine Nicholas Caritat, the marquis de Condorcet.

1789 July 14

The storming of the Bastille took place, marking the beginning of the French Revolution that continued until 1799. Among the demands of the people who overthrew the French king was a demand for fair weights and measures.

The cry of the peasants throughout France on the eve of the Revolution was an old one first used in 1302: *One King, one law, one measure, and one weight.*

In the midst of the French Revolution, the National Assembly of France requested the French Academy of Sciences to: … *deduce an invariable standard for all the measures and all the weights.*

This resulted in the French revolutionary government supporting the development of a decimal metric system that has stood the test of time and has gradually evolved into the predominant measurement system in the world.

The Baron de Breteuil was recalled to the King's service and from 1789 July 11 to July 16 (for 6 days!), he was the King's chief minister. Three or four days after the storming of the Bastille, the Baron fled France. The last service he was able to provide to his King was to act as a mission to the other European sovereigns; for this he was entrusted with a literal *'Carte blanche'*, a blank sheet of paper carrying nothing but the King of France's signature. Following the Baron de Breteuil's departure from France, the Pavillon de Breteuil became state owned.

When the Estates General assembled in 1789, the commoners, representing the Third Estate, declared that they were the only legitimate representatives of the people, and they succeeded in having the church and the nobles join them in the formation of the National Assembly. The new National Assembly began drafting a new French constitution.

Following the French revolution, the new democracy decided to introduce new, universal measures. French scientists, like their colleagues in other European countries, had been considering a new, universal measuring system for more than 120 years, since John Wilkins published his idea for a '*universal measure*'. At the same time, measurement and science had become even more precise. Science, especially the geographers, needed a trusted basis of measurement. Trade and commerce were also greatly impeded by the bewildering array of measures, often with the same name, but describing different quantities. It has been estimated that in France alone, about 250 000 different measurement units were in use at the time. This situation was probably matched by an equal chaos in Germany and other nations.

Benjamin Franklin became President of the 'Society for Promoting the Abolition of Slavery' and wrote an anti-slavery treatise.

1789 August 4

Feudalism was abolished in France. The French National Assembly passed laws that did away with the feudal system of land management that had been the way that things were managed in France since ancient times. These laws were augmented with further laws passed in May 1790 that completed the abolition of feudalism. These laws meant that the local '*seigneurs*' no longer had a monopoly on weights and measures. It also effectively meant that France had no method of measurement at all. This lack of any measurements led to an intolerable legal vacuum and lawlessness.

This void somehow had to be filled, and this had to be done against a background where many were attempting to safeguard their numerous vested interests. As the new National Assembly was seeking to fulfil the dreams of progressive thinkers they were simultaneously trying to satisfy the aspirations of the bourgeoisie. And all participants were fully aware of their complaints because they had only recently been powerfully expressed in the *cahiers de doléances*. Many had complained about the metrological duplicities of the *seigneurs,* and the situation had grown worse in many provinces during the Revolution, because of the '*seigneurial reaction*', as the seigneurs jockeyed to gain the best possible post-revolutionary position. The task was gigantic and not all the difficulties were at first appreciated.

1789 August 14

Jean Baptiste Le Roy (1720/1800), who was a physicist, a mathematician, and who at one time had been a clockmaker, suggested that the Academy propose to the National Assembly that they dissolve all the old measures currently in use in France and replace them all with the length of a pendulum that beat seconds at the 45th parallel of latitude. It is likely that the Academy's secretary, the marquis de Condorcet, drew up this proposal and asked Talleyrand to present it as the Academy's proposal to the National Assembly. Talleyrand also proposed that the British be invited to join in the determination of the correct length and in promoting the use of the new measure '*so that all nations might adopt it*'.

1789 August 27

The *Declaration of Rights of Man and Citizen* was enacted in France as the new French Constitution.

1789 October 56

During the 'October Days' in France, there was a women's march on the Palace of Versailles and King Louis XVI was brought back to Paris

1789-93

By the end of 1789, Franklin's Fugio cents were in wide circulation throughout the USA, so Jefferson's decimal currency was well established by the time George Washington was inaugurated as the nation's first president on 1789 April 16.

Thomas Jefferson became the first Secretary of State for President George Washington after his return from France. During his term as the first Secretary of State, Jefferson proposed a decimal-based measurement system for the USA. See:

http://ourworld.compuserve.com/homepages/Gene_Nygaard/t_jeff.htm
for the full text of Jefferson's proposal and see
http://en.wikipedia.org/wiki/Plan_for_Establishing_Uniformity_in_the_Coinage,_Weights,_and_Measures_of_the_United_States for the Wikipedia discussion of this plan.

1790

Talleyrand, Bishop of Autun, made a report to the Constituent Assembly on the state of French weights and measures, and in it suggested a new measure of length based on the length of the seconds pendulum at the latitude of 45°N. He also suggested that the Academy of Sciences in Paris collaborate with the Royal Society of London in defining the new unit. The Assembly, and subsequently Louis XVI, approved this proposal, but nothing came of it.

George Washington, in his first message to Congress on January 8, reminded the legislators of their responsibility on weights and measures when he said:

> *A uniformity of weights and measures 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, it must be no less honourable to the public council than conducive to the public convenience ... 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.*

George Washington repeated his call for uniformity in the currency, weights, and measures of the United States of America with similar calls for action in his second and third annual presidential messages to congress (later these annual reports became known as the '*State of the Union Address*').

George Washington was clearly referring to an idea similar to Wilkins' '*universal measure*' when he said, '*derived from a standard at once invariable and universal*'.

The Congress accepted that decimal currency had been agreed between the states in 1785 but that uniform standard measures remained a problem. The USA Congress discussed which weights and measures to use for the USA and then responded to George Washington's speech by asking Secretary of State, Thomas Jefferson (1743/1826), to make a special report on the subject of measurement for the USA. Jefferson presented his report to Congress on July 13. Congress had the authority to decide on a standard of weights and measurement as a Constitutional right, under Article I, Section 8.

1790 February 9

The Prieur du Vernois (1763/1832), later known as the Prieur de la Cote-d'Or, made a suggestion to the National Academy of France for a single uniform set of weights and measures. His proposal was based on a seconds pendulum timed at the Paris Observatory. The pendulum was to be divided into thirds to make a Paris foot (which would also be the national foot for France). The French foot was to be divided into 10 inches, each of 10 lines; and 10 feet would be equal to 1 rod. This suggestion has a remarkable similarity to that made earlier by Thomas Jefferson to the USA Congress.

1790 March 28

King Louis XVI issued a decree that abolished, without compensation, all feudal rights with respect to weights and measures.

1790 March 29

Talleyrand, Bishop of Autun, put Prieur's suggestion to the French National Assembly. In doing so he adjusted it slightly, making the length of the pendulum a standard length at a latitude of 45 degrees. Talleyrand did this to make the proposal independent of any particular location.

Talleyrand's proposal was referred to the French Committee on Agriculture and

Commerce, who recommended it to the king, who sanctioned action on August 22.

At this time, Talleyrand was also aware that both the UK and the USA were investigating the possibility of new methods of measuring. He actively encouraged the idea that the governments of the UK, the USA, and France should work together with the French Academy of Sciences and the Royal Society in London to create a new system of universal measure.

The House of Commons in England again discussed a proposal from Sir John Riggs Miller to establish uniform weights and measures throughout England and Scotland.

Knowing that Sir John Riggs Miller had raised the question of weights and measures in the British House of Commons during 1789, Talleyrand, Bishop of Autun, wrote this private letter to him. This is Sir John Riggs Miller's translation of Talleyrand's letter.

> *Sir,*
>
> *I understand that you have submitted for the consideration of the British Parliament, a valuable plan for the equalization of measures: I have felt it my duty to make a like proposition to our National Assembly. It appears to me worthy of the present epoch that the two Nations should unite in their endeavour to establish an invariable measure and that they should address themselves to Nature for this important discovery.*
>
> *If you and I think alike on this subject, and that you are of opinion that much general benefit may be derived from it, it is through you only that we can hope for its accomplishment; and I beg to recommend it to your consideration. Too long have Great Britain and France been at variance with each other, for empty honour or for guilty interests. It is time that two free Nations should unite their exertions for the promotion of a discovery that must be useful to mankind.*
>
> *I have the honour to be, Sir, with due respect, your most humble and obedient servant,*
>
> *The Bishop of Autun*

Talleyrand's proposals for a new measuring method were based on a survey he had done on the measures currently in use in France. The mess they were in can be gauged from this quote from *The Measure of Enlightenment* by J. L. Heilbron.

> *The existence of French men and women around 1790 was made miserable by, among other things, 700 or 800 differently named measures and untold units of the same name but different sizes. A 'pinte' in Paris came to 0.93 litre; in Saint-Denis, to 1.46; in Seine-en-Montagne, to 1.99; in Précy-sous-Thil, to 3.33. The aune, a unit of length, was still more prolific: Paris had three, each for a different sort of cloth; Rouen had two; and France as a whole no fewer than seventeen, all in common use and all different, the smallest amounting to just under 300 lignes, royal measure, the largest to almost 600.*
>
> *France possessed non-uniform measures in law as well as by custom. Their multiplicity went with other relics of the feudal system, which maintained arbitrary rents and duties usually to the disadvantage of the peasant. A landlord wanted his bushels of grain or hogsheads of beer in the biggest measures in use in the neighborhood, and he preferred to sell according to the smallest. Nor were all seigneurs above enlarging the vessel in which they collected their rents; and since in many cases they possessed the only exemplars of their patrimonial bushel, no one could be certain that it did not grow in time. But one suspected. A frequent complaint in the cahiers, or notebooks of desiderata brought by representatives of the people to the meeting of the Estates General in 1789, was that 'the nobles' measure waxes larger year by year. These same representatives castigated the oppressive confusion*

> *of customary measures as barbaric, ridiculous, obscurantist, gothic, and revolting, and demanded an end to them, and the establishment of a system of unchanging and verifiable weights and measures throughout the country, or at least throughout their region. Many urged that the King's measure, the royal foot, be made the law of the land.*
>
> *Sharpers and crooks whose practices were not sanctioned by ancient rights and wrongs and middlemen acting in analogy to money changers opposed the rationalization that menaced their livelihood.*

Talleyrand's concept was for the adoption of a brand new basic standard, '*pris dans la nature*' (*derived from nature*) and therefore acceptable to all nations. Talleyrand further suggested that the French National Assembly, the English Parliament, and the Royal Society of London should undertake preliminary work towards this objective jointly. He wrote:

> *Perhaps this scientific collaboration for an important purpose will pave the way for political collaboration between the two nations.*

1790 April 13

The French National Assembly sent proposals to Britain, Spain and the United States to propose cooperation on units of measurement. The first parliamentary reference to metrication in the UK was on 1790 April 13. This was when parliamentarian Sir John Riggs Miller put to the British Parliament the proposition that England and France should cooperate to equalise their weights and measures, by the joint introduction of the metric system. Such cooperation was rejected by the Parliament in London.

Sir John Riggs Miller reported to Parliament on the receipt of the letter from Talleyrand, and expressed himself in favour of the scheme. He then made a speech to the British House of Commons proposing extensive measurement reform. Riggs Miller had been in contact with both Talleyrand in France and Thomas Jefferson, who was then the first Secretary of State of the United States of America. Thomas Jefferson had served as Ambassador to France from 1785 to 1789, when he was in regular contact with English and French intellectual leaders of the Enlightenment as they formed their ideas about universal measurement.

At about the same time Talleyrand, Bishop of Autun and one of the foremost members of the French National Assembly, introduced the subject and launched a debate on measurement. His report to the French National Assembly included a detailed analysis of the extremely muddled state of French weights and measures. Talleyrand proposed to the National Assembly a decimal system of stable, unvarying and simple measurement units. These were to be based on the length of the seconds pendulum at 45° North latitude beating a second.

This resulted in a directive to the French Academy of Sciences to prepare a report on the development of a system of measurement for France and for the world. Talleyrand argued that the French National Assembly should charge the French Academy of Sciences with: *... the task of establishing a measuring system, which could be acceptable to the whole world.*

1790 April 14

At a public meeting of the National Academy of Sciences on April 14, Mathurin Jacques Brisson (1723/1806), one of the Commissioners from the French Academy of Sciences, read out a statement on the uniformity of weights and measures for all of France.

1790 April 17

Benjamin Franklin died. Twenty thousand people attended his funeral in Philadelphia.

The French National Assembly favoured the idea of a new measuring system. Louis XVI authorised scientific investigations aimed at reform of all French weights and measures and these investigations led to the development of the 'decimal metric system' as the legal measurement system, firstly in France with the passage of several laws mostly in the 1790s, and then in the rest of the world. Talleyrand also suggested that the Academy of Sciences in Paris collaborate with the Royal Society of London in defining the new measuring unit.

A French politician, La Rochefoucault, had this to say in the National Assembly in support of Talleyrand's proposal:

> *We cannot make enough haste over promulgating this decree, which should bring about fraternal relations between France and England.*

Even though it was in the middle of the French revolution, the National Assembly of France requested the French Academy of Sciences to deduce an invariable standard for all the measures and all the weights and to prepare a report on the development of a system of measurement for France and for the world. The French National Assembly then sent delegates to Britain, Spain and the USA to propose cooperation in developing a universal system of units for measurement.

1790 May 8

The Assembly decided that the length of the metre would be defined by a seconds pendulum. Having held a detailed discussion on the proposal submitted by Talleyrand, they approved the proposal to standardize the length of the new metre as the length of a pendulum with a one-way swing (called a half-period) of one second; a pendulum that swings back and forth in one second is about 250 mm in length. The decree was later ratified (see 1790 August 22) in a form that was, in almost every respect the same as Talleyrand's proposition .

The National Assembly recognised that the metric system was simple and elegant with decimal multiples and sub-multiples based on Greek prefixes (deca-, hecto-, kilo-) for multiples and Latin (deci-, centi-, milli-) for fractions. They were also impressed with the relationship between length, volume, and mass as 1 gram (mass) was defined as one cubic centimetre (volume) of water.

Some maintain that this was the day that the metric system was 'born' with the statement:

Liberté! Egalité! Métriqué!

The National Assembly of France made this decision to go ahead with the metric system after the revolutionary storming of the Bastille (1789 July 14) but before the declaration of the French Republic (1792 September 22) and the execution of King Louis XVI (1793 January 21).

Prior to this decision, under the monarchy and the *ancien régime*, French people had used inches (pouce ~27 mm), feet (pied ~325 mm), and fathoms (toise ~1950 mm). Later, on a recommendation from the French Academy of Sciences, the assembly redefined the metre in 1793 as 1/10 000 000 of the distance from the Equator to the North Pole.

Charles-François, marquis de Bonnay (1750/1825) delivered a report to the French National Assembly on the measurement proposition proposed by Talleyrand.

There were five distinct aims that were focused on in the discussions of the metric system at this time. In order of importance they were:

- uniform national standards of measurement for France,
- a natural standard of length that was not based on the length of a king's foot (the hated *pied de roi*),
- the use of a decimal scale to divide units into smaller parts or to multiply units into

larger parts,

- the creation of an international system of weights and measures for trade,
- the emerging requirement for scientists and engineers to have access to better accuracy and precision in their measurements.

Today we often think that two of these, decimalisation and internationalisation are most important, but politically in 1790 it was the first two that appealed to the revolutionary spirit of the times. The wishes of *le philosophes* (*the scientists*) were essentially ignored in the political process that made the metric system legal in France.

Talleyrand sent Sir John Riggs Miller a copy of the National Assembly's minute of May 8 referring to the new measurement arrangements. In this minute the French king, Louis XVI, was asked to write to the British king, George III, inviting joint action to determine a natural standard of weight and measure. However, subsequent historians have not been able to find such a letter in the Royal Archives at Windsor Castle.

At the same time as the French National Assembly considered the Academy proposal as presented by Talleyrand, they also considered several other similar proposals including one by the military engineer, Prieur, who expressly opposed using an arc of the meridian as the basis for a standard of length. Prieur wrote:

> *Besides the magnitude of the fundamental operation required, the difficulty of verifying it, and the impossibility of doing so daily, it is not easy to decide how exact the method might be.*

Thomas Jefferson agreed with Prieur when he wrote:

> *... the various trials to measure various portions of meridians, have been of such various result, as to show there is no dependence on that operation for certainty.*

1790 July 13

Thomas Jefferson reported back to the Congress with a '*Plan for Establishing Uniformity in the Coinage, Weights, and Measures of the United States*'. You can find full details of Jefferson's plan at: **http://avalon.law.yale.edu/18th_century/jeffplan.asp** and at **http://ourworld.compuserve.com/homepages/Gene_Nygaard/t_jeff.htm**

In the first paragraph of his report, Jefferson provides evidence of the international effort to develop a decimal metric system between France, the UK, and the USA. Jefferson wrote:

> *... on the 15th of June, came to my hands, from Paris, a printed copy of a proposition made by the Bishop of Autun, to the National Assembly of France, on the subject of weights and measures; and three days afterwards I received, through the channel of the public papers, the speech of Sir John Riggs Miller, of April 13th in the British House of Commons, on the same subject.*

Although Jefferson's report carried considerable influence in the Congress of the USA, as he was the first Secretary of State of the USA for President George Washington, no official action was taken, and the Congress passed no legislation relating to weights and measures as a result of Jefferson's report.

Jefferson's report used some of the scientific investigations aimed at reform of the French weights and measures, but it varied in the detail. Jefferson's proposals also had a remarkable similarity to the design for a '*universal measure*' outlined by John Wilkins in 1668. It seems likely that Jefferson had access to *An Essay Towards a Real Character and a Philosophical Language* (1668) by John Wilkins.

This conjecture seems more likely when we compare Wilkins' plan for length with that of Jefferson.

Wilkins' plan	Jefferson's plan
Let this Length therefore be called the Standard; let one Tenth of it be called a Foot; one Tenth of a Foot, an Inch; one Tenth of an Inch, a Line. **And so upward, Ten Standards should be a Pearch; Ten Pearches, a Furlong; Ten Furlongs, a Mile; Ten Miles, a League, & c.**	Jefferson defined a standard length using a seconds pendulum then he wrote: *Let the foot be divided into 10 inches; the inch into 10 lines; and the line into 10 points. Let 10 feet make a decad; 10 decads one rood; 10 roods a furlong; and 10 furlongs a mile.*

And there are many other parallels. In many respects Jefferson's plan might have been taken straight from John Wilkins' essay with only slight changes to the names of the various components of the plan and a few minor differences. For example Jefferson suggested a pendulum that had a rod instead of a string. Details of Wilkins' plan can be found in the article *Commentary on 'Of Measure' by John Wilkins* and a Wikipedia article on Jefferson's decimal plan can be found at:
http://en.wikipedia.org/wiki/Plan_for_Establishing_Uniformity_in_the_Coinage,_Weights,_and_Measures_of_the_United_States

Note: I have been unable to definitely confirm that Jefferson had access to Wilkins' Essay. Jefferson was a very keen book collector and I, and several very helpful librarians, have searched many catalogues of his extensive collections. I suspect that he either owned or had access to Wilkins' *Essay*, and that possibly his copy of Wilkins' book was lost in the Library of Congress fire of 1851
(http://www.loc.gov/exhibits/jefferson/jefflib.html)

Jefferson recommended a two-part decimal plan to Congress.

- The first part of Jefferson's plan proposed the adoption of a universal length based on the seconds pendulum, and measured at 45 degrees North latitude at sea level and changing existing old English units to this new universal measure.
- The second part of Jefferson's plan proposed the use of a decimal system as a basis for dividing and multiplying the seconds pendulum length unit: *to reduce every branch to the same decimal ratio, thus bringing the calculations of the principal affairs of life within the arithmetic of every man who can multiply and divide plain numbers.*

Thomas Jefferson's plan might have been successful in the USA as his system actually resembled the metric system in many ways. However, it had a fundamental problem that had nothing to do with the metrology or the mathematics of his proposal; the problem was with the language he chose for his new system. He presented a decimal system developed around a new '*foot*' based on a pendulum that swung from one end of its arc to the other in a second (about 250 millimetres long). Jefferson's system had many names for different units and all of them had been used as measuring words in the past. He did not seem to realise that as most people do not comprehend the theory of measurement, they will cling fiercely to their use of old measuring words, without understanding what they exactly mean. It is a pity that Jefferson had not acquired the idea of using prefixes to create names for sub-multiples and multiples of his units, or the history of measurement in the USA might have been profoundly different.

Here are some samples of the basic units in Jefferson's new measuring system:

Length

Jefferson divided his pendulum-based new foot into 10 new inches. Each new inch was to be divided into 10 new lines, and each line into 10 new points. For longer lengths, 10 new feet were to be called a decade, 100 new feet was a new rood, 1000 new feet a new furlong, and there were 10 000 new feet in a new mile.

At about 250 millimetres, Jefferson's new foot was slightly shorter than the old foot (about 300 millimetres) that was commonly used in the USA at that time, and a mile of 10 000 new feet was almost twice as long as an old mile.

Capacity and volume

Jefferson described a basic volume unit that he called a new bushel, and its size could be traced back to the new foot, as the new bushel was defined as a new cubic foot.

Jefferson's system resembled the developing metric system, in which a litre of water weighs 1000 grams. The cubic new foot, that Jefferson called a bushel, would have a capacity of about 15.6 litres and would hold about 15.6 litres of water. This meant that a thousandth part of the new bushel would have a volume of about 15.6 millilitres and it would hold about 15.6 grams of water. This is about half the size of the old ounce and the old fluid ounce that were used in the USA. The new bushel was close to 75% of the size of the bushel then in use in the USA.

Mass (then called weight)

Jefferson defined the basic 'weight' as a new ounce that was one thousandth part of a new bushel (1 cubic new foot). This meant that the basic weight unit was the ounce, defined so that a bushel of water weighed 1000 ounces.

As the metric system developed later during the 1790s as a legal entity in France, I have no doubt that the French '*philosophes*' borrowed extensively from Jefferson's ideas as they developed their proposals for the development of the metric system as the legal measurement system for France.

Congress gave the Jefferson plan serious consideration but took no action to implement it. Without a coherent measurement policy, the USA simply adopted bits and pieces from various versions of English weights and measures. These included:

- distance measurements identical to those of the 1592 English Act of Parliament,
- mass measures based on English avoirdupois weight measurements of 1303,
- measurements for dry volumes based on the 1496 English '*Winchester*' bushel and
- measurements for liquid volumes based on the English Queen Anne wine gallon of 1707.

It is remarkable that Congress never established this traditional method, or any other method, as the mandatory system of weights and measures for the United States.

During the nineteenth century expanding trade needed a consistent set of international measurement standards. This need was gradually filled by the use of the metric system, which quickly spread throughout continental Europe. Citizens of the USA, during the 19^{th} and 20^{th} centuries, only became aware of the metric system if they imported or exported goods to or from Europe.

George Washington and Thomas Jefferson combined forces politically to propose the use of decimal currency for the USA. Decimal currency became reality in the USA with the establishment of the Federal Mint in 1792.

1790 August 12

A deputation from the French Academy of Sciences was made to the French National Assembly with the view to placing the services of the Academy of Sciences at the disposal of the National Assembly.

During the next eight days, the French National Assembly issued instructions that allowed municipal authorities to fix the rates for assessing weights and measurements in public squares and markets.

1790 August 12

The French National Assembly passed laws that entrusted municipal authorities with the verification of weights and measures.

1790 August 22

The French King Louis XVI authorized scientific investigations aimed at a reform of French weights and measures. Talleyrand's proposal to the French National Assembly was to standardize the length of the seconds pendulum at 45° latitude. His proposal, having been referred to the Committee on Agriculture and Commerce, was recommended to the king who sanctioned action. This was the French decree that led to the further development of the metric system.

The French Academy of Sciences was made responsible, and appointed a committee that consisted of: Jean Charles de Borda (1733/1799), Joseph-Louis Comte de Lagrange (1736/1813), Pierre-Simon Laplace (1749/1827), Gaspard Monge (1746/1818), and Marie Jean Antoine Nicholas Caritat, marquis de Condorcet (1743/1794). Condorcet, who was appointed secretary, was a champion of modernity whose vision of progress reflected commitment to the values of reason, freedom, and equality. Condorcet's proposals for social and political reform were characterized by pragmatism and by the conviction that only cautious and scientific management of change would ensure lasting benefits. Condorcet was also a close friend of Thomas Jefferson, who had been the Ambassador from the USA from 1784 to 1789.

The committee‘s first report, in October, recommended the decimal division of money, weights, and measures. However, it should not be inferred that this was a smooth or an easy process. Stephen Hawking in his book, *God created the integers*, describes Laplace's contribution to the metric system as follows:

> *Engrossed as he was in science, Laplace had little time for the tumult of politics in the late 1780s and early 1790s. He took no part in the affairs of the French Revolution during its most radical phase in the early 1790s, except to participate in the committee that devised the metric system, part of a systematic attempt to overthrow the shackles of the Old Regime. One camp argued that the fundamental unit of length should be defined in terms of the earth's equatorial circumference. Laplace argued, instead, that given the role of the right angle in geometry, the fundamental unit of length should be based on the length of the quadrant from the North Pole to the equator.*
>
> *Thanks to Laplace's successful argument, the metre was defined as 1/10 000 000th of the distance from the pole to the equator. By the end of 1793 the political atmosphere in Paris became too intemperate for Laplace. Along with many other leading scientists, including the chemist Antoine Lavoisier and Coulomb, Laplace was purged from the committee devising the metric system. The radical republicans loudly announced that such responsibilities could only be entrusted to men known for 'their Republican virtues and hatred of kings'.*
>
> *Literally fearing for his neck, Laplace and his family fled from Paris to the country town of Melun, thirty miles* [actually a little over 40 km] *away. In retrospect, Laplace had correctly judged the probabilities of the possible outcomes. His friend and colleague, Lavoisier, chose to remain in Paris, where he lost his head to the guillotine in the spring of 1794.*

The National Assembly decreed that all measures in use throughout the provinces of France should be sent to the Academy of Sciences, who would then issue new standard measures to all the parishes of France. The idea was that by doing this the old measures could be dispensed with altogether. However, it seems that the National Assembly had little idea of the complexity and magnitude of this task. They considered that the new standards could be adopted, and copies of it could be distributed replacing all of the old measures with the new within six months.

1790 October 27

The National Assembly accepted Talleyrand's proposal to standardize the length of the seconds pendulum at 45° latitude. and sent it, and a question about the most useful division of weights, measures, and monies to the committee. The committee recommended to the Assemblée that currency, weights and measures should all be based on a decimal rather than a duodecimal system and included a list of prefixes for decimal multiples and sub-multiples

The French Academy of Science then issued a report that recommended the decimal division of French money along similar lines to those used in the USA.

1790 December 8

The French National Assembly issued a decree limiting the application of the law of 1790 May 8 to only the principle measures in each district, with a requirement that a report be filed for all other measures.

On March 30 the committee specifically rejected the seconds' pendulum because it involved time as a non-linear element and recommended:

> *... that the length of a meridian from the North Pole to the Equator be determined, that 1/10 000 000th of this distance be termed the metre and form the basis of a new decimal linear system, and, further, that a new unit of weight should be derived from the weight of a cubic metre of water.*

One reason for choosing the quadrant was because one of the commission members, Jean-Charles de Borda, had constructed extremely precise graduated circles for measuring angles, exactly the kind required for this sort of work. de Borda's circles were graduated in units called 'grads' with 100 centesimal grad divisions to a quadrant. de Borda sneered at the Babylonian degrees used by others as too old-fashioned (in 1790) to be used for the development of the modern *decimal metric system*, which was to be both scientific and simple. The committee proposed:

- to redo the arc from Dunkirk to Perpignan and to extend it to Barcelona,
- to obtain latitudes astronomically,
- to lay out new baselines,
- to observe the pendulum,
- to determine the weight of an exactly measured volume of distilled water at the temperature of melting ice, and
- to compare all the old units in use in France with the new standards.

Essentially, except for the last point, this committee was putting in place the proposal that Bishop John Wilkins had made for a *'universal measure'* in 1668. They were sufficiently confident of their methods that they did not seek international cooperation before they wrote:

> *... we have excluded from our advice every arbitrary determination, we have used only the common property of all nations ... In a word, if the memory of all our work disappeared and only the results remained, they would disclose nothing to show what nation conceived the idea and carried it through.*

The Commissioners assigned the name, *metre*, to the unit of length that was one ten-millionth of the distance from the North Pole to the equator along the meridian running near Dunkerque in France and Barcelona in Spain.

All the components were now in place for the decimal metric system that later became the International System of Units (SI) that is now used in every nation in the world.

Later developments included more units, more prefixes, better definitions, and the development of a property called *coherence* between all units. The latest version of the modern metric system, approved in 1960, is called the Système International d'Unité (SI) in French or the International System of Units (SI) in English. Note that the abbreviation SI is the same for both French and English.

The units for volume and mass were derived from the unit of length, relating the basic units of the system to each other and to nature. For example, the first metric unit of mass, the *gram*, was defined as the mass of a cube that was 0.01 metre on each side, filled with water at its temperature of maximum density. Later, the cubic decimetre – a cube 0.1 metre on each side – was chosen as the unit for volume or capacity and this was given the name, *litre*.

Multiplication or division of the base units by 10s, 100s, and 1000s formed larger and smaller multiples of each unit. The use of decimal numbers simplified the use of the metric system for users of the system, by eliminating calculations such as dividing by 16 (to convert ounces to pounds) or by 12 (to convert inches to feet). The metric system was designed as a 'decimal' or 'base-10' system.

Talleyrand again urged that the preparation of a new system of weights and measures should be a collaborative venture, with the French inviting the participation of the English Parliament and the Royal Society of London. Talleyrand also made efforts to establish contacts with other countries. These included negotiations with Thomas Jefferson concerning the definition of the metre.

Jefferson initially favoured using a pendulum at the latitude of 38°N as this was close to the centre of the territory of the United States of America, but eventually he accepted the 45°N, proposed by the French National Assembly as he felt that this was better suited to an international destiny for the metric system.

1791

The Pavillon de Breteuil had been occupied by a detachment of the French army and it was left in a very poor condition. A contemporary report stated,

> *… they have entirely destroyed the wood panelling and partly burnt the floor boards for heating and have removed the locks so that there are substantial repairs to be made …*

The French Academy of Science did not immediately accept the recommendations of its committee:

> *… that the length of a meridian from the North Pole to the Equator be determined, that 1/10 000 000th of this distance be termed the metre.*

Some of them objected that the arc had received enough attention in previous studies. Some argued simply that the pendulum was easier to use and to understand. Finally, however, the Academy endorsed the committee's recommendations and forwarded them to the French National Assembly without alteration.

But the Academy did not let go of the seconds pendulum easily. They decided to determine the length of a seconds pendulum at the Paris Observatory, to serve as a secondary reference, even though the primary reference was to be one ten-millionth of the distance from pole to equator.

The Académie des Sciences Française adopted the length committee's recommendations and a second report by the Académie recommended that the standard of length be:

> *one ten-millionth of the meridian quadrant.*

One reason they gave for this choice was that the metre would materialise the idea of

> *... a unit which in its determination was neither arbitrary nor related to any particular nation on the globe.*

The Académie des Sciences committee also recommended a new decimal system of measurement based on the metre and the kilogram. Discarding the traditional degrees and minutes of angle measurement emphasized the decimal nature of the new system.

The length of the metre was to be based on the measurement of a meridian arc extending from Dunkerque to Barcelona. This was an extension of the line measured by Lacaille and Cassini in 1740.

Ideally, of course it would have been better to survey the whole quadrant between the North Pole and the equator but no one had ever been to the North Pole.

The scientific commission members reckoned that if they could measure a significant piece of a meridian, the rest could be calculated. Both ends of the line to be measured had to be at sea level, and near the middle of the pole-to-equator quadrant.

Fortunately for them, the only one such meridian on Earth is about a tenth of the distance from the pole to the equator and it runs from Barcelona to Dunkerque, so most of the distance lies conveniently inside France (a fact that did not escape the notice of observers such as Thomas Jefferson).

The committee rejected the pendulum, on principle, because it involved non-linear time and because it was insufficiently precise. To stress that this was to be a *decimal métrique système* the committee recommended dividing the quadrant decimally into grads of one hundredth of a quadrant.

They specifically recommended discarding the degrees, minutes, and seconds of Babylonian angle measurement.

The secretary of this committee, Condorcet, wrote in this report:

> *The Academy has done its best to exclude all arbitrary considerations – indeed, all that might have aroused the suspicion of its having advanced the particular interests of France; in a word, it sought to prepare such a plan that, were its principles alone to come down to posterity, no one could guess the country of its origin.*

The French National Assembly endorsed the Academy of Sciences' report and directed that the necessary measurements of the Earth's meridian be made as soon as possible. In a single day of debate, the French National Assembly enacted the necessary legislation on 1791 March 26.

Although the Académie des Sciences finally chose that a metre would be exactly a 1/10 000 000th of the distance between the North Pole and the equator, so that this distance would be exactly 10 000 000 metres, an error was made in its measurement.

The error arose because the wrong value was assumed for the earth's flattening used in correcting for oblateness. We now know that the quadrant of the earth is 10 000 957 metres instead of exactly 10 000 000 metres as was originally planned.

At this time the French unit of volume was called the pinte and this was later renamed the litre; it was defined as the volume of a cube having a side equal to one-tenth of a metre.

The unit of mass was called the grave and this was later renamed the kilogram; it was defined as the mass of one litre of distilled water at the temperature of melting ice.

The centigrade scale for temperature was also adopted with its fixed points at 0 °C and 100 °C representing the freezing and boiling points of water; this is now called the Celsius temperature scale.

When the French National Assembly accepted the report of the Académie des Sciences adopting a length equal to a quadrant of the meridian as the base of the new system of measures they said:

> *The only hope of extending the standardization of measures to foreign nations and persuading them to accept it lies in selecting a unit that is in no way arbitrary, nor particularly suited to the circumstances of any one nation.*

The metric system, as it was first proposed by John Wilkins in England, and developed in France (with help from the USA) in the 1790s), was designed as a standard universal system that would be easy for everyone in the world to understand and to use.

In fact, when Talleyrand presented the plan for a system of decimal metric units to the French National Assembly he described it as:

> *... an enterprise whose result should belong some day to the whole world.*

The (gloriously named) French mathematician and philosopher, Marie-Jean-Antoine-Nicolas de Caritat, marquis de Condorcet (1743/1794) wrote an article '*Le Mètre: du monde*' (The metre: of the world) where he described the metric system simply as:

For all time, for all people

In 1799 the international metric system conference decided that a medal should be struck to honour the metric system and bearing the words of Condorcet:

A TOUS LES TEMPS, A TOUS LES PEUPLES

It should be noted that, from a purely metrological point of view, using a quadrant of the earth as a standard makes little sense. To measure this distance is so difficult that any two surveys of such a long distance are bound to differ by much more than the amount of precision required of the unit.

The amazing thing about this is how two 18th century surveyors, Delambre and Méchain, would come so close to the true measurement in such trying circumstances. It took them six years to complete the measurement of the distance from Dunquerque to Barcelona using triangulation techniques.

A committee of 12 mathematicians, geodesists, and physicists met with Louis XVI, who gave his formal approval for the introduction of the new metric system on June 19 . A day later Louis and his family attempted to flee secretly from France to Germany, but were recognized and captured at Varennes. He was returned to Paris where he remained as constitutional king until 1792.

1792

In August 1792 the National Assembly abolished the office of King. Louis was arrested (August 10). From his prison cell, Louis XVI issued the proclamation that directed two astronomers and engineers, Jean-Baptiste Delambre and Pierre François-André Méchain, to perform the operations necessary to determine the length of the metre.

Delambre and Méchain set to work to measure the precise distance, on the meridian, from Barcelona in Spain to Dunkerque in northern France. In part the line from Barcelona to Dunkerque was deliberately chosen to be multinational to make people aware that the French scientists were not simply being parochial.

Delambre and Méchain emphasised the decimal aspect of the metric system by discarding the traditional degrees and minutes of angular measurement. They used a process called triangulation, where they had to measure angles in each of the triangles very accurately. They did this using decimal division of the quadrant. The quadrant was divided into 100 grads (that were sometimes called grades or gons) and these were further divided into 100 decimal minutes, each of 100 decimal seconds. This gave them a theoretical precision of one millionth of a quadrant.

However, both Delambre and Méchain were fully aware that measuring the Earth is a very complex operation. They knew that the Earth is not a perfect sphere or ball. Isaac Newton had already pointed out that the Earth bulges near the Equator and is flattened near the poles. Mountains and valleys make the actual shape ev en more uneven.

Every single measurement made by Delambre and Méchain had to be adjusted to assume that the lengths were measured at sea level. They, and the other members of the French Academy of Science, were aware that the distance between the North Pole and the Equator depended on which meridian you used to measure it. For example, the distance from the North Pole to the Equator measured through London is not the same as the distance measured through their chosen cities of Dunkerque and Barcelona.

Delambre and Méchain knew that it was not possible to measure an accurate distance from the North Pole to the Equator to arrive at a precise figure for the metre. Their goal was to find the best approximation possible at the time. Obviously, they knew that they could not measure all the way from the Equator to the North Pole. They could only measure the distance from Dunkerque to Barcelona as accurately as they could, to give them an indication of the full distance, then guess the rest, as the distance from Dunkerque to Barcelona is only about 11% of the actual distance from the North Pole to the Equator.

The survey proved extremely difficult as wars, both civil and foreign, hampered the operation. To give a flavour of these difficulties, here is an extract from a letter that Méchain wrote to Delambre about working in the mountains:

> *You could not have an idea of the difficulty we have to procure wood and workmen for the transportation and establishment of signals on the summits of the mountains. We are obliged to go on foot almost everywhere. Moreover, it is a pysical impossibility to make certain stations such as Burgarach, which we could not reach except by hanging on to branches and underbrush and by climbing rocks. Night and day we are exposed to storms, having for a bed only a little straw, and for shelter a simple tent. We are often interrupted and tormented by the clouds, which envelop one of the stations and hang over it for entire days. The south wind is terrible in these regions; nothing resists its violence. It is necessary to strike the tents and descend on hands and knees if one does not wish to be carried away as a feather.*

At one point Delambre and his crew were accused of plotting to restore the monarchy because they used white flags to make their survey markers easily visible but, as everyone knew, white was the colour of the deposed royal family.

In September Delambre was arrested. Released after getting new official papers, Delambre and Méchain were again threatened with arrest shortly afterwards and accused of spying, since their instruments were thought to be suspicious.

They obtained new official papers from the National Assembly and then continued their mission, only to find that the Committee of Public Safety decreed that

> *... government officials* [must] *delegate their powers and functions solely to men known to be trustworthy for their republican virtues and their abhorrence of kings ...*

and removed Delambre and Méchain from their measurement task.

Eighteen months later they were reinstated and carried out their work for the next two years, completing it finally in April 1798. The task of Delambre and Méchain was to have been completed in a few months, but it took six years and five months. They published the results in three volumes between 1806 and 1810 and presented the first volume to Napoleon, who remarked: *Conquests will come and go but this work will endure.*

These days the length of the Earth's quadrant can be measured fairly quickly and easily using satellite technology. Satellite measurements show that the metre is actually about

0.0002 shorter than a metre based on one ten-millionth of the earth's quadrant (999.9998 mm instead of 1000 mm).

In hindsight, Delambre and Méchain did a magnificent job. They knew that the metre that they would define would not be exactly 1/40 000 000 of the Earth’s circumference as the other three quarters of this circumference – that they couldn't measure or even estimate – might have different lengths. This meant that the metre might not be exactly equal to 1/10 000 000 of the distance from the North Pole to the Equator.

Given these difficulties, all they had to work with were de Borda's highly accurate instrument, the 'Borda Duplicating Circle', for measuring the angles at each angle in a triangle and then used these angles to determine lengths by calculation.

Delambre and Méchain were also aware that there is the possibility of error in every measurement we make and their goal was to minimise these errors. Working in decimals of right angles divided into 100 grads (rather than having to use the old Babylonian degrees, minutes, and seconds) markedly reduced the possibility for error.

However, since the 1790s, astronomers and sailors have continued to use the older non-decimal Babylonian measures of angles with 360 degrees in a circle, 60 minutes of arc (also called arcminutes) in a degree, and 60 seconds of arc (also called arcseconds) in a minute. Scientists, other than astronomers, have decided not to use decimal divisions of a quadrant or the older Babylonian methods and have developed several other methods: the radian as the ratio between an arc of a circle and its radius, decimal degrees such as 12.345 degrees, and angular mils are still in use in various sciences and technologies.

King Louis XVI also issued orders for Baron Gaspard Clair François Marie-Riche de Prony (1755/1839) to begin the task of calculating new mathematical tables for use with the metric system.

He calculated the trigonometrical tables by organizing his (human) 'computers' in three levels. Skilled mathematicians laid down the rules for the calculations; second level mathematicians calculated the functions for every 10th value; and level three mathematicians carried out the interpolations for the intermediate values using finite differences – where they were only required to add and subtract.

In the USA, Thomas Jefferson wrote that he was not enamoured of the international metric system as it was formulated, primarily because the meridian had been substituted for the pendulum as the standard. A USA Senate committee declined an invitation from France to participate in developing an international metric system.

The Congress of the USA established the United States Mint to produce new coins and notes. By then Jefferson's decimal system had been already well established in the thirteen states by the daily use of Benjamin Franklin's 'Fugio Cent'. The world's first decimal currency, with one dollar consisting of 100 cents, was introduced smoothly and successfully to the USA.

1792 September 22

The French Republic was established when Year 1 of the First Republic was proclaimed on the day of the autumnal equinox.

1793

The French Constitution was promulgated with Jean-Antoine Nicolas de Caritat, Marquis de Condorcet (who as stated earlier is usually known simply as Condorcet) as the principle author. Condorcet was an especially close friend of Thomas Jefferson from the USA. Their friendship is logical when you consider that Thomas Jefferson had played a leading role in forming the ideas behind the Constitution of the USA in 1787. The Library of Congress web site (**http://www.loc.gov/exhibits/jefferson/jefffed.html**) says:

Although Thomas Jefferson was in France serving as United States minister when the Federal Constitution was written in 1787, he was able to influence the development of the federal government through his correspondence. Later his actions as the first secretary of state, vice president, leader of the first political opposition party, and third president of the United States were crucial in shaping the look of the nation's capital and defining the powers of the Constitution and the nature of the emerging republic.

For example, these words of the preamble are attributed to Thomas Jefferson:

We hold these truths to be self-evident, that all men are created equal, that they are endowed by their Creator with certain unalienable Rights, that among these are Life, Liberty and the pursuit of Happiness.

It also seems highly likely that Condorcet and Jefferson would have discussed their common ideas for the system of *universal measure* that eventually became SI, the modern metric system.

France and England went to war.

The New York Stock Exchange opened this year, but they decided not to use this new-fangled decimal currency. Instead they chose to use dollars of the USA but to divide them into 'pieces-of-eight'; that is into halves, quarters, and eighths. The NYSE did not change to trading using decimal currency until 2001 – 208 years later.

1793

Louis XVI was executed on January 21.

On August 1 the metre had its legal origin when the Republican Government of France adopted a report from the Académie Française and decreed the unit of length was to be called the 'metre' and it was to be 1/10 000 000 (10^{-7}) of the earth's quadrant.

Despite their best efforts, the scientists at the time made an error in their calculations, namely the assumed value of the earth's flattening used in correcting for oblateness. The quadrant of the earth is nearer to 10 002 kilometres instead of exactly 10 000 kilometres as originally planned (an error of 0.02%) so the metre was a little short at 999.8 millimetres rather than 1000 millimetres exactly. For details of the history of measuring the Earth circumference see **http://en.wikipedia.org/wiki/Spherical_Earth**.

In the meantime, while they waited for the meridian to be measured, the French government passed laws approving a provisional measuring system and a provisional metre was constructed from geodetic data already available. A brass standard of the provisional metre was made and it is still preserved in the Conservatoire des Arts et Métiers at Paris. The National Convention also adopted the preliminary definitions and terms with the '*methodical*' nomenclature, using prefixes for fractions and multiples of the measuring unit names, rather than the '*common*' method that involved separate names for each unit size.

On August 8 the National Convention abolished the Academy of Sciences as un-republican. But the Committee of Public Safety (CPS) wanted to rid France of the old feudal measures, and they needed the help of the members of the Academy to do this, so the CPS persuaded the National Convention to create the *Commission temporaire des poids et mesures républicaines* (Temporary Commission of Republican Weights and Measures) with the same members.

Later, when Lavoisier was arrested in November and the commission requested his release, the CPS responded by kicking five more members off the commission, including Delambre.

A report, '*Le Système Métrique Décimal*', published by the Ministère du Commerce et Industrie in Paris in 1901, said in part:

Standard metres and graves (kilograms), made by the temporary Commission, were very probably distributed, at least in part, in several foreign countries. In the papers of the Committee of Public Safety, kept in the National Archives, there is a mention under the date of 21 frimaire year I (11 December 1793), that a copper metre and a copper grave both with gradations were sent to the USA through an agency for a 'Correspondent of the Natural History Museum 'Joseph Dombey'.'

Joseph Dombey, a French citizen and botanist, as a special diplomatic messenger; accepted the task of transporting some of the provisional metric standards to Philadelphia, the first capital of the USA. Unfortunately, a hurricane forced his ship south to Guadeloupe and Dombey was imprisoned at Montserrat where he died. The French recovered some of his papers and metric models some years later but an opportunity to be relevant to the USA was lost.

1794

Paolo Ricchini de Voghera sent a letter from Italy to Champagny, the Minister for the Internal Affairs of the French Empire, extolling the virtues of the metric system and bemoaning the variety of measures used in Italy at that time. He wrote:

This Gothic diversity was the ineluctable outcome of the partition and fragmentation of Italy into small seigneuries, as well as a direct consequence of the feudal law.

He went on to demand tough measures anticipating strong resistance from conservatives and traditionalists.

The execution of Robespierre ended of the reign of terror in France.

Condorcet suspected that he was being watched by his enemies and although he fled from Paris he was arrested and imprisoned. Two days later, on March 29, he was found dead in his prison cell and it is not known whether he died from natural causes, was murdered, or took his own life. More information can be found at:
http://www-history.mcs.st-and.ac.uk/Biographies/Condorcet.html
where H B Acton summarised Condorcet's life as follows:

Wholly a man of the Enlightenment, an advocate of economic freedom, religious toleration, legal and educational reform, and the abolition of slavery, Condorcet sought to extend the empire of reason to social affairs. Rather than elucidate human behaviour, as had been done thus far, by recourse to either the moral or physical sciences, he sought to explain it by a merger of the two sciences that eventually became transmuted into the discipline of sociology.

However, for many students of the metric system and its development, the secretary of the scientific commission that developed the first legal metric system, Jean-Antoine Nicolas de Caritat, Marquis de Condorcet will be best remembered for describing the metric system as:

For all time, for all people

1795

For years after the decision by the Borda committee to base the length of the metre on a meridian that went from Dunquerque to Barcelona, there was criticism of the decision for being too French-centric, as this meridian passed suspiciously close to Paris.

The French scientists argued that:

There is nothing here that can give the slightest pretext for the reproach that we wished to assert any sort of dominance.

Specifically they argued:

⊇ the section should extend equal distances on either side of the 45th parallel because there the seconds pendulum and the size of a degree have their mean values;

- ⊇ it is a coincidence that the 45th parallel runs through France;
- ⊇ only there do meridians have arcs bisected at 45° that terminate at either end at sea level; and
- ⊇ only there are there meridians that are short enough to measure.

Pierre-Simon,Marquis de Laplace put it this way in a lecture in 1795:

> *... had savants from all countries come together to fix the universal measure, they would not have made a different choice.*

However, not everyone in the rest of the world agreed with them. It was hard for people in places other than Paris to concede that a section of the meridian through Paris and lying almost entirely within France was a unit dictated by nature! As an example, Thomas Jefferson put his position like this:

> *The element of measure adopted by the National Assembly excludes, ipso facto, every nation on earth from a communion of measurement with them; for they acknowledge themselves, that a due portion for admeasurement for a meridian crossing the forty-fifth degree of latitude, and terminating at both ends at the same level, can be found in no other country on earth but theirs.*

The UK passed the Weights and Measures Act 1795

On April 7 the Republic of France legally adopted the French Academy of Sciences recommendation for a decimal metric system. This decimal metric system defined the length, mass, and capacity standards and listed the prefixes for multiples and submultiples of units. The law (Loi du 18 germinal, an III) adopted the definitions and terms that we still use. Lenoir made a brass bar to represent the provisional metre, obtained from the survey of Lacaille, and a provisional standard for the kilogram was derived.

Copies of the provisional standards were sent to several countries, including the United States.

The motto adopted for the new decimal metric system was Condorcet's description of the metric system as:

For all time, for all people

The new law defined the 'Système métrique décimal', to distinguish it from the several 'systèmes métriques' of former times that were not 'décimal'. The new measures were officially named 'républicaines'.

The French Assembly decreed that henceforth the new 'Republican Measures' were to be legal measures in France. This law included the **metre** for length, the **are** (100 square metres) for area, the **litre** for volume, the **gram** (and later the **kilogram** for mass), and the **bar** for pressure, as the official base units.

All of these units were related to the metre. For example the kilogram was the mass of distilled water occupying a space of one litre. In the form of a cube, a litre is 100 mm high by 100 mm long by 100 mm wide.

Prefixes were identified with Greek words for the multiples:

deca (x 10), hecto (x 100), kilo (x 1 000), and myria (x 10 000);

and Latin prefixes for fractions:

deci (1/10), centi (1/100), milli (1/1 000).

This was the decimal metric system, which proved to be simple to use, and made transitions between different dimensions easier beyond compare. The metric system has survived little changed as the basis of today's Système International d'Unités (SI).

The Assembly re-established the scientific commission (except for Lavoisier, guillotined the previous year) and ordered resumption of the survey of the quadrant.

The new French coinage, including the decimal franc, was also introduced as the French legal currency.

1797

The UK passed the Weights and Measures Act 1797.

1797-1801

Thomas Jefferson was Vice President for President John Adams.

1798

Delambre and Méchain completed the survey (despite the great difficulties due to the political conditions) of the meridian of longitude between Barcelona and Dunkerque.

In the whole of the quadrant survey, only angles had been measured, the angles of thousands of contiguous triangles stretching all the way from Barcelona to Dunkerque. All that was needed was the measurement of any side of only one of these triangles then the dimensions of all the others could be calculated, and from them the distance along the meridian. Delambre used a special ruler to measure one of the baselines – it took him 33 days to measure a single line with sufficiently high accuracy and precision.

Scientists met in Paris in September to discuss the Delambre and Méchain survey findings to confirm the metric standards and definitions. They held a conference on the *decimal metric system* that is now believed to be the first international scientific conference ever held anywhere in the world.

Before the conference many of the visiting international scientists inspected the progress that had already been made following contributions from the UK (Wilkins), from the USA (Franklin and Jefferson), and from many scientists in France. The international scientists also took the opportunity to visit French educational and scientific laboratories and to tour major French industrial facilities.

The international delegates included: Henricus Aeneae from the Batavian Republic; Balbo, Mascheroni, Multedo, Franchini and Fabbroni from Italy; Thomas Bugge from Denmark; Ciscar and Pedrayes from Spain; Trallès from Switzerland; and Jean Henri van Swinden from the Netherlands. There were also delegates from the Cisalpine Republic, the Ligurian Republic, Sardinia, and Tuscany.

The French scientists, including Coulomb, Mechain, Delambre, Laplace, Legendre, and Lagrange, who had already been working on the decimal metric system for some years, joined these international scientists for the conference.

Although scientists from the UK and from the USA did not specifically take part in this meeting, contributions to the decimal nature of the system and its overall structure had been discussed by Benjamin Franklin and Thomas Jefferson, in person in the 1780s and by correspondence since then. Contributions had also been made through correspondence from other nations such as the UK.

An international meeting of experts was called on November 28 to consider Delambre's and Méchain's survey results. One of the meeting's committees consisted of four persons, each of whom independently calculated the length of the metre from the measurements, and from certain assumptions about the shape of the earth; their calculations agreed.

Two commissions were set up in France.

The first of these, chaired by Jean Henri van Swinden (1746/1823) from the Netherlands, checked the results of Delambre and Méchain who had completed the measurement of the arc of meridian so that the exact length of the metre could be determined. Platinum and iron standards of the metre were then constructed. Van Swinden's committee also considered the issue of the metric prefixes.

Thomas Jefferson had coined the words ‘cent’ to mean one hundredth and ‘mil’ to mean one thousandth, and Prieur de la Côte d'Or, a former military engineer, had also suggested a prefix for a tenth (deci). Van Swinden further developed these and they became the basis of the current range of prefixes that we use for both multiples and for sub-multiples. More were added at the suggestion of the British Association for the Advancement of Science (the BAAS) in 1874.

The second commission, chaired by Trallès from Switzerland, made the determination of the mass of the kilogram. They carefully measured the mass of a cube of distilled water at the temperature of melting ice that was one-tenth of a metre on each side (100 mm x 100 mm x 100 mm). The size of this container became the standard for the litre and the mass of the water became the standard for the kilogram. Based on the mass of this amount of water, a platinum kilogram was constructed.

1799

The USA Congress passed the 'Surveyors Act', the first federal weights and measures law. It used the units: *inches*, *feet*, and *yards*.

The Royal Institution was founded in London with the task of exploring scientific and technical advances that were applicable to:

> *... the application of science to the common purposes of life.*

However it did not see that the establishment of national standards in weights and measures was one of these issues.

J. P. Hobert and L. Ideler published, '*Nouvelles tables trigonometriques*' in Berlin. This gave natural and log sines, cosines, tangents, and cotangents to 7 decimal places, and also natural sines and tangents for the first hundred ten-thousandths of a right angle.

Van Swinden presented his report on length on April 30. He reported that the survey of Delambre and Méchain led to fixing the definitive length of the metre, based on the best estimate that could be made at that time of the distance from the North Pole to the Equator.

Subsequent examination has shown that there were some errors made in the survey of the length of the Earth's quadrant. Considering the difficulties of measuring any Earth meridian, it was decided that instead of altering the length of the metre to maintain the 1/10 000 000 ratio, the metre would simply be defined as the distance between two marks on a precisely made platinum bar. This platinum bar would then become the world standard metre.

The '*Metre of the Archives*' was a platinum bar with a rectangular cross section and polished parallel ends, and a metre was the distance between the polished end faces at a specified temperature. It was the international standard metre for most of the 19th century, and was compared to other bars with optical comparators as a means of disseminating the metre.

Trallès presented his volume and mass report on May 30.

With the formal presentation to the Assembly of the standard metre, as determined by Delambre and Méchain, the metric system became a fact on June 22 when the standard metre was formally deposited in the National Archives of France.

Following the reports from earlier in the year, Janety and Lenoir made standards of the metre and the kilogram. The new standards were presented to the Council on June 22 by a delegation of French and European scientists led by Van Swinden of The Netherlands.

On the same day, the standards of the metre and kilogram were deposited in the Archives of the Republic. These two standards can be seen as a major step in the development of our present Système Internationale d'Unités.

The length of the metre is now measured more precisely in terms of the speed of light but its length has remained the same. The '*Kilogram of the Archives*' that is also known as '*Le Grand K*' remains the world standard for mass.

Three government officials, one of whom was Napoleon Bonaparte, signed the law establishing the metre and the kilogram as the official units of measure in France. As a result of this law the metre and the kilogram of the Archives became the legal standards for measurement in France and subsequently for the rest of the world.

Copies of both the metre standard and the kilogram standard were also made and provided to the scientific delegates to take home to their governments.

Since this date, 1799 June 22, there has been no attempt to change the length of the metre as the world standard for length. The only changes have occurred when more exact measuring methods became available.

Although the metre has not changed in length, its precision has become much greater as new scientific methods became available.

Following a scientific conference, with representatives from Denmark, Italy, the Netherlands, Spain, and Switzerland, to validate the metric system's physical foundations and to design prototype standards, the metric system became a legal fact in France.

In the decree of 1799 December 10 the French National Assembly specified that the length of a platinum metre bar, deposited in the National Archives 23 June 1799, was the final standard of length for the metre. The first time that the words '*metric system*' were officially used was in the text of this legislation.

From France the metric system soon spread to become the universal language of measurement of all countries. For example, the département of Dyle (in Brussels, Belgium) made the metric system legally binding on the same day as the legislation was passed in France.

1800

A Julian leap day was skipped in 1800 and this changed the start of the UK tax year from April 5 to April 6. With the characteristic efficiency of the financial community, this date has not been changed since then. The financial community still uses fractions such as quarters and halves in interest rates despite the introduction of the easier to use decimal numbers into England in 1608.

The Coast Guard and Geodetic Survey of the USA obtained metre and kilogram standards from France as the basis for mapping of the coast of the USA.

1801

C. Borda and J. B. J. Delambre published *Tables trigonometriques decimales* in Paris. This gives sines, cosines, tangents, cotangents, secants, and cosecants at intervals of 1 centesimal (1 hundredth) of a quadrant to 7 decimal places. Borda and Delambre also give seven-figure logarithms of all the numbers to 10,000.

1801-09

Thomas Jefferson became President of the USA where, among other things, he negotiated the Louisiana Purchase that doubled the size of the USA.

1803

France adopted decimal currency with centimes, decimes and francs. Prior to this they had used 12 deniers to equal one sol, and twenty sols to equal one livre. The changeover went smoothly as one sol became five centimes and twenty of them became one franc instead of one livre. France subsequently successfully introduced decimal currency to a number of other countries occupied during the Napoleonic period, and a large number of European nations had adopted decimal currency by 1815.

1804

Delambre published *Decimal trigonometrical tables* to extend Borda's work toward rational decimal measurements of angles, instead of the old Babylonian division into degrees, minutes, and seconds. Borda divided a right angle into 100 grades, each degree into 100 centigrades, and each centigrade by decimal fractions. Borda's system required new trigonometrical tables to be constructed; Borda organised these calculations and the new trigonometrical tables were published by Delambre in 1804.

In a letter to Sir Joseph Banks, the president of the Royal Society, Matthew Flinders suggests that the name *Australia* should replace the name *New Holland* that was previously used. The name *Australia* appears in the 1806 *Philosophical Transactions of the Royal Society*.

1805

Ferdinand R. Hassler, a Swiss immigrant to the USA, brought a standard metre back home from a visit to Europe. This standard metre was a gift from his friend J. G. Tralles, who had been the Swiss delegate to the 1799 International Institute on the Metre in Paris. Because Tralles had chaired the institute's committee on the construction of the standard metres he was given two, when each of the other delegates was given only one standard metre to take home. Hassler presented his standard metre to the Philosophical Society of Philadelphia for safekeeping.

John Dalton (1766/1844) proposed his theory that substances are made from atoms.

Wikipedia at **http://en.wikipedia.org/wiki/John_Dalton#Atomic_theory** lists the five main points of Dalton's atomic theory as:

- Elements are made of tiny particles called atoms.
- All atoms of a given element are identical.
- The atoms of a given element are different from those of any other element; the atoms of different elements can be distinguished from one another by their respective relative weights.
- Atoms of one element can combine with atoms of other elements to form chemical compounds; a given compound always has the same relative numbers of types of atoms.
- Atoms cannot be created, divided into smaller particles, nor destroyed in the chemical process; a chemical reaction simply changes the way atoms are grouped together.

Most, but not all of these ideas are still in use by chemists and physicists.

1806

Dominique François Jean Arago (1786/1853) travelled to Spain to complete the measurement of an arc of meridian of the Earth, that had not been quite completed by Delambre and Méchain. Arago's additional measurements took from 1806 till 1809. Later, Arago became director of the Paris Observatory.

1807

Ferdinand R. Hassler became superintendent of the newly organized Coast Survey, so the Philosophical Society of Philadelphia returned the standard metre to him to use in the survey. The Coast Survey used this standard metre to verify other measures until 1890, when it was placed in the vault of the Bureau of Standards.

1809

Jean Baptiste Joseph Delambre reported the time for light to travel from the Sun to the Earth as 8 minutes and 12 seconds. This yields the speed of light as just a little more than 300 000 kilometres per second. Its modern value is exactly 299 792.458 kilometres per second.

1809

On August 17 the Mayor of Turin declared that from 1809 October 1 the metric system would be obligatory.

1809-26

At Monticello, Thomas Jefferson drew up plans, supervised construction, and outlined curriculum of the University of Virginia.

1811

Thomas Jefferson outlined his ideas for a decimal system of measurement in a letter to Dr. Robert Patterson (See: **http://www.let.rug.nl/usa/P/tj3/writings/brf/jefl212.htm**) in which he writes:

> *What ratio shall we adopt for the parts and multiples of this unit? The decimal without a doubt. Our arithmatic* [sic] *being founded in a decimal numeration, the same numeration in a system of measures, weights and coins, tallies at once with that. On this question, I believe, there has been no difference of opinion.*

Peter Barlow writes about the Decimal System in his book: *An Elementary Investigation of the Theory of Numbers: with its application to the indeterminate and Diophantine analysis, the analytical and geometrical division of the circle, and several other curious algebraical and arithmetical problems* (J. Johnson and Co, London 1811),.

1812

Following protests about the new system of measurement, Napoleon Bonaparte temporarily suspended the compulsory provisions of the 1795 metric system law by decree. This decree gave the illusion that he had decided to go back to the old ways and reintroduce '*mesures usuelles*' such as the aune, the boisseau, the livre, and the toise.

However, in reintroducing the names of the old units, Napoleon also had the old names redefined in metric terms. Length, for example, was measured using a two metres toise (fathom), and mass by a 500 gram livre (pound). The toise was divided into 6 pieds (feet) that were each one third of a metre in length. A decree was also issued that the legal decimal system must be taught in schools and used in all official transactions.

France now had three separate measuring methods and a major problem:

- all of the hundreds of old pre-1790 measures,
- the metric system (of 1799),
- the Napoleonic *mesures usuelles*, and
- all of the thousands of conversion factors between all of these units.

To the French public it seemed that there were far too many separate methods to measure anything, and this complicated program of different measures led to total confusion in measurement in France, eventually leading to demonstrations, riots, and even deaths. The confusion lasted about a generation before the metric system was once again reinstated as the sole means of measurement in 1837, with a cut-off date in 1840, and its position in France has never been threatened again.

Gradually neighbouring countries realised the simplicity of the metric system and it spread rapidly (in historical terms 200 years is not a long time) to the rest of the world.

The French army retreated from Moscow.

1813

Ferdinand R Hassler brought a brass bar, called the Troughton scale, from England to the USA to use as a standard for the English Imperial yard. He used the 36 inches between the twenty-seventh and the sixty-third inch marks on an 82-inch brass bar as his standard yard. The secretary of the treasury reported that this bar:

> *... had been compared with the pendulum vibrating seconds in London and also with the French metre, which is based upon measurements of arcs of a meridian of the earth.*

1814

In France, the decree of 1814 July 4 made it clear that the popular meaning of the word 'métrique' had shifted from being any system of measurement to referring to the system based on the metre. (Strangely, in 21st century use, the word metric is regaining some of its original meaning – referring to any measurement in economic jargon such as (say): *'We will use the unemployment metric as one of the metrics for the whole economy.'* **http://en.wikipedia.org/wiki/Metric**

The government of the USA bought a standard bar from Troughton's of London. It was a bronze bar, 82 inches long, with an inlaid silver scale.

1815

Ferdinand Hassler had brought the 82 inch Troughton's bar to the USA as he intended to use it as the standard for the Coast Survey of the USA. He defined the 'yard' as the distance between the 27th and 63rd inch marks on the 82 inch scale. This copy of Troughton's bar served as the unofficial standard of length for the USA from 1832 until 1856. It was presumed to be identical with the English yard (the one preceding the Parliament fire) but that apparently had not been checked by direct comparison.

The UK passed the Weights and Measures Act 1815

1816

On 1816 February 21 the French government made a major step backwards; the metric system was banned from use in retail shops. In the place of the metric system, shops were to use the old collection of units, which were to be known as the '*Mesures Usuelles*'. Metric units, although still used, were outlawed by government decree. The French ban on the use of metric units in French shops was not repealed until 1825 and the 'Mesures Usuelles' were not made illegal until 1837.

On 1816 August 21, the Netherlands passed a law that would make that country metric from the beginning of 1820. Before 1816, the Netherlands used both old and metric units. From 1810 to 1813, the Netherlands was a part of France and both old units and metric units were legal under French law. Belgium and Luxembourg, also converted to metric measures at this time.

President James Madison in his 1816 congressional message said:

> *Congress will call to mind that no adequate provision has yet been made for the uniformity of weights and measures contemplated by the Constitution. The great utility of a standard fixed in nature and founded on the easy rule of decimal proportions is sufficiently obvious.*

A report was published from the UK Select Committee on the *Original Standards of Weights and Measures.*

1816-17

Another '*Great Recoinage*' was proposed for the UK. Pushing for a decimal currency, Mr J Wilson Croker expressed his view in the House of Commons, that:

> *... it would be almost unpardonable for the legislature at this time to re-enact and legalise anew these barbarisms in the division of our coin which were attended with great inconvenience.*

1817

Captain Henry Kater FRS (1777/1835) conducted pioneering research in England to improve the precision of weights and measures. In particular he aimed to improve the seconds pendulum so it could be used as a standard of length all around the world. A seconds pendulum is just under a metre in length and it is made so that one beat (half a period) of the pendulum takes exactly one second.

By 1817, the length of the seconds pendulum was known with sub-millimetre accuracy. By then it had been measured in many places around the world and by many famous people. These included Isaac Newton, Marin Mersenne, Giovan Battista Riccioli, Jean Picard, Jean Richer, Gabriel Mouton, Christiaan Huygens, Jean Cassini, Nicolas Louis de Lacaille, Jacque Cassini and Charles-Marie de La Condamine.

Lacaille and Cassini measured the length of the seconds pendulum in Paris in 1740 (latitude 48°N) as the equivalent of 993.83 mm; Isaac Newton measured the length of the seconds pendulum at 45°N as the equivalent of 993.53 mm; and La Condamine during the Peru expedition made a measurement at the equator of 990.65 mm.

Henry Kater was the first to design and use a compound or invariable pendulum. Kater's pendulum was reversible, which meant that once it had been used to determine the absolute intensity of gravity at a particular place, the same pendulum could then be used to establish the comparative intensity of gravity in other places.

One of Kater's first experiments was to determine the length of a seconds pendulum in London. He found that this length was 39.13929 inches (about 994 millimetres depending on which inch he used).

Under Henry Kater's instructions, Thomas Jones made a series of 13 invariable pendulums and these were '*swung*' in many parts of the world, because the earth is not a perfect sphere – the force of gravity varies slightly from one place to another. Using one of Kater's pendulums, the force of gravity was determined in many parts of the world, leading to a much better understanding of the shape of the earth.

For example, Invariable Pendulum No. 10 was used by Sir Thomas Brisbane to conduct pendulum experiments at Parramatta when he was Governor of New South Wales in Australia from 1821 to 1825. Pendulum No. 10 was also taken on an Atlantic voyage, an expedition to the Euphrates, and on James Clark Ross's Antarctic expedition.

The congress of the USA requested the Secretary of State, John Quincy Adams, to recommend a system of weights and measures for use in the USA.

1819

The 'First Report' of the Commissioners appointed to consider weights and measures in the UK was presented to Parliament.

1820

The 'Second Report' of the Commissioners appointed to consider weights and measures in the UK was presented to Parliament.

1821

Following a four-year investigation, John Quincy Adams wrote a comprehensive report for Congress. Ferdinand R. Hassler, who helped John Quincy Adams prepare the report, probably knew more about the history and use of measures than any other American alive at that time.

This report dealt with the modernisation of the measurement system of the USA and included some thoughts on 'the metric question'. Here is an excerpt from John Quincy Adams' '*Report on Weights and Measures by the Secretary of State, made to the Senate on February 22, 1821*':

> *Weights and Measures may be ranked among the necessaries of life to every individual of human society. They enter into the economical arrangements and daily concerns of every family. They are necessary to every occupation of human industry; to the distribution and security of every species of property; to every transaction of trade and commerce; to the labors of the husbandman; to the ingenuity of the artificer; to the studies of the philosopher; to the researches of the antiquarian; to the navigation of the mariner; and the marches of the soldier; to all the exchanges of peace, and all the operations of war. The knowledge of them, as in established use, is among the first elements of education, and is often learned by those who learn nothing else, not even to read and write. This knowledge is riveted in the memory by the habitual application of it to the employments of men throughout life.*

When Quincy Adams presented his '*Report Upon Weights and Measures*' to the USA Congress he recommended consideration of the international metric system. Specifically he wrote:

> *The (metric) system approaches to the ideal perfection of 'uniformity'. (It) will shed unfading glory upon the age … Considered merely as a labor-saving machine, it is a new power, offered to man, incomparably greater than that which he has acquired by the new agency which he has given to steam. It is in design the greatest invention since that of printing.*

Quincy Adams' report then recommended that no immediate change in the system of weights and measures be made, arguing that the people of the United States were not yet ready for the metric system. He considered that it would be premature for the United States to adopt the metric system before it proved to be successful in practice in other parts of the world. It is probable that the French reversion to the '*mesures usuelles*' in 1812 greatly influenced Quincy Adams and the Congress of the USA. But for Napoleon's '*mesures usuelles*', the USA could well have changed to metric measures in 1821.

In the UK, the 'Third Report' of the Commissioners appointed to consider weights and measures was presented to Parliament.

1822

Charles Babbage, in 1822, decided that the job of calculating mathematical tables should be done by machine. Babbage invented the difference engine to do this work and later he invented the analytical engine. These computing engines were the world's first programmable computers. The first computer programmer in the world was Ada (Countess) Lovelace. Ada was the daughter of the English poet, Lord Byron. Unfortunately, Charles Babbage never completed any of his computing engines because he kept adding improvements.

1823

Charles Babbage demonstrated his '*Difference Engine*', a mechanical means of computing mathematical tables, to the Royal Society. Later, Babbage designed Analytical Engines that could store programs.

1824 June 17

In the UK the Weights and Measures Act 1824, during the reign of George IV, (1820 – 1830) established new methods of measuring for the UK and for the British Commonwealth. It declared the avoirdupois pound and the yard as 'Imperial Standards'. The three basic units were the pound avoirdupois, the yard, and the second. This Act also phased out many of the old measuring words.

The Imperial unit of length was defined as the length of the prototype of the imperial yard made by Bird in 1760. All length measures were to be based on this prototype yard.

The Imperial unit of capacity, the gallon, was defined as the volume of 10 pounds avoirdupois of distilled water, weighed in air against brass weights at a temperature of 62°F and atmospheric pressure of 30 inches of mercury. This definition of the gallon might be interpreted as Britain's response to the decimal metric system but it is the only factor of ten used in the Imperial system; quarts and pints remain as quarters and eighths of an Imperial gallon.

The state of New South Wales in Australia obtained standards of mass, length and volume from England to develop an Australian measurement system. As other Australian states developed their own measurement methods, it was soon recognised that a national measurement system was needed.

1825

France again allowed the use of metric units, but it did this alongside the '*Mesures Usuelles*' that had been introduced in 1812. France now had dual measures.

George Stephenson put James Watt's high-pressure steam engine on rails in his 'Locomotion No. 1', which was the first steam locomotive to carry both passengers and freight on a regular basis. This led to railways being built all around the world. By the 1830s, London even had steam driven buses, one of which was named the '*Automation*'. By the end of the 19th century, steam technology was well enough developed that the Stanley Steamer competed with cars with gasoline engines for several years.

Sir John Wrottesley introduced a motion into the UK House of Commons to: ... *inquire how far the coin of the realm could be adapted to a decimal scale.*

Sir John wanted the pound to be divided into ten double-shillings (later called Florins), each of 100 farthings. In response, the Chancellor of the Exchequer agreed to unify the currencies of Britain and Ireland, so that there would no longer be thirteen English pennies to an Irish Shilling.

1825

The UK Weights and Measures Act 1825 came into force in the UK and in all of its colonies on May 1.

1826

Thomas Jefferson died on July 4, on the 50th anniversary of the signing of the Declaration of Independence.

Thomas Jefferson never lost interest in the issue of decimal measurement, although discussion of it in the USA grew less and less as he grew older. In the book, *Jefferson And The Rights Of Man,* Dumas Malone writes this about Thomas Jefferson:

> *When writing his autobiography as an old man, he noted that everybody had readily comprehended the odometer he used in travelling which divided the mile into "cents," and concluded that the people would have soon got used to a decimal system of weights and measures.*
>
> *Perhaps nothing short of revolution could have overcome inertia sufficiently to cause such a system to be established, and there was no revolution in America in this decade as there was in France.*
>
> *Thus Jefferson lost a title to fame which he might have cherished more than any of the political honours he gained or the offices he held.*

1827

Georg Ohm (1787/1854) in *Die galvanische Kette, mathematisch bearbeitet* (*The*

Galvanic Circuit Investigated Mathematically), published what is now known as Ohm's law. He used an electrochemical cell (invented by Alessandro Volta in Italy), with other equipment he designed and built, to determine the direct proportionality between the potential difference (now often called the voltage) applied across a conductor, and the resultant electric current.

Albert Gallatin, Minister of the USA in London, sent a Troy pound to the USA Mint at Philadelphia.

1827

Ferdinand R. Hassler wrote in a letter that was published in the *New York American on* January 08:

> *The nation that shall exclude from itself the admission and use of foreign talents and knowledge, must always remain behind in the paths of civilization, and will appear comparatively barbarous, if not really become so. Sciences, arts, and ideas for improvements, are the common property of all nations – their mutual ties – and cannot be successfully cultivated without free intercourse, exchange, and intermixture ... Every civilized nation of Europe has contributed its share to that happy mixture of knowledge and ideas of improvements, that has caused the character of this country to rise to so high a standing.*

1828

Ferdinand Hassler recognised the Troy pound as '*an exact copy of the imperial troy pound of Great Britain*'; it was adopted for use as the basis for new coinage of the USA.

An Act was passed by the House to establish this Troy pound as the standard of mass for the USA Mint. This was the only USA law officially adopting a standard of any of the old weights and measures. The British yard, avoirdupois pound, and the Winchester gallon were approved as the basis for USA customs duties.

1830

By 1830, tariffs on imports into the USA were in a mess. They were far from being uniform because ports in different states were using different ways of measuring. Importers used these differences to cheat the system by choosing ports that used bushels with the greatest number of cubic inches for importing such things as grain and sugar. As a result, importers became rich, commerce suffered in other ports, and the U.S. Treasury suffered from loss of revenue.

The Senate ordered the Treasury Department to inspect the customs houses and to compare the weights and measures used in them. As a result, President Andrew Jackson chose Ferdinand R. Hassler, a minor official in the Treasury Department, to lead a survey of customs houses. As a basis for his work, Hassler got his standard metre back from Pennsylvania. It was recognised that part of his work would be to formulate the first standardisation of measurement for the USA. This survey uncovered quite a variety of '*standard pounds*' in the various customs houses. In the USA, the Office of Standard Weights and Measures was formed and formal standardisation began under its control. In the following years, a new standard pound was dispatched to each of the customs houses and also to the governor of each state.

1832

By administrative action, the Secretary of the Treasury declared the yard, the avoirdupois pound, and the Winchester bushel to be the official system of weights and measures for the USA.

The legal yard of the USA was defined as the distance between the lines 27 and 63 of a bronze bar, 82 inches in length that had been brought from England for the Federal Survey Department in 1813.

The only standard pound in the USA was the Troy pound that was defined as 5760 grains. The avoirdupois pound was defined as 7000 grains so, as the USA did not have a standard avoirdupois pound, it was simply defined as 7000/5760 Troy pounds,.

Charles Babbage, in his book, '*On the Economy of Machinery and Manufactures*', recommending changing to decimal measurements and decimal currency.

1833

The German mathematician, Karl Friedrich Gauss (1777/1855) strongly promoted the application of a metric system, together with the astronomical second, as the unit of time for use in science. His system was based on millimetres, grams, and seconds, and he devised a coherent system of units for the physical sciences. The millimetre and the gram were defined by the standard metre and kilogram and Gauss added the astronomical second.

Examples of Gauss' use of this coherent system included absolute measurements of the earth's magnetic force. In later years, Gauss and Wilhelm Eduard Weber (1804/1891) extended these measurements so that the system could also include electrical phenomena. Gauss especially promoted these units for the physical sciences because they were coherent.

In the USA, the Treasury Department directed Hassler to construct and distribute standards of length, mass, volume, and balances by which masses might be compared, to all of the states.

1834

Less than ten years after the establishment of Imperial measures, the UK Houses of Parliament burned down on October 16, and the three standard measures, the yard, the pound and the gallon, that defined British measures, were destroyed. In particular, Bird's yards – the 1758 and the 1760 – were both destroyed, so the UK and all the colonies had no standard for length. This despite the fact that the 1824 Act of Parliament that legalized the 1760 bar as the standard for England, had made a provision that, in the event that Bird's bar was lost or destroyed, it should be replaced using the pendulum method to determine its length. This was not done.

The UK passed the Weights and Measures Act 1834.

1836

Belgium, Holland, and Luxemburg withdraw official use of all old measures in favour of the metric system.

1837

Napoleon's armies were again forced to retreat from Moscow and Napoleon was banished to Elba.

The new emperor, Louis Phillipe, made the use of the decimal metric system obligatory with a law passed on 1837 July 4. This law also declared the '*Mesures Usuelles*' illegal in France and ordered that the only units to be used in France were to be units of the decimal metric system. France once again changed to the 1799 metric system, with a law that strictly banned all the old non-metric measures and the Napoleonic measures from 1840 January 1 onwards. From that date using old measures became a penal offence.

1838

A survey of Switzerland found that the Swiss foot had 37 different regional lengths and the Swiss ell had 68 different lengths There were 83 different Swiss measures for dry grain, 70 different measures for liquids, and 63 different measures for weights.

Starting this year, standards representing units of length, capacity, and mass (troy and avoirdupois) were manufactured and delivered to each of the states of the USA. The length and capacity standards were based on the metre and the mass (weight) was based on the Troy pound in the mint of the USA.

1839

When William Henry Fox Talbot described his process of 'photogenic drawing' to the Royal Society, Sir John Herschel recognised his invention as '*the first new art form in centuries*' and quickly renamed it '*photography*'.

1840

The metric system was reinstated as the compulsory measurement system of France on January 1. French people who did not use the decimal metric units were threatened with large fines and severe penalties. It was illegal to use or even own non-metric weights and measures. Non-metric units were banned in public and private correspondence. Inspectors were empowered to confiscate old weights and measures. Schools and business adopted the new system rapidly and it has been used in France ever since. It had taken France just under 50 years to change to metric.

Greece, the Netherlands, and Italy changed to the metric system.

1841

The USA finally received a complete set of the official French standards. These included a steel metre that had been compared with the metre of the Conservatory of Arts and Measures, and a standard kilogram that had been compared with the kilogram of the French Archives.

1844

The last English standard, the *Imperial Standard Yard*, was manufactured in bronze in 1844. This new *Imperial Standard Yard* was to replace the previous standard that been destroyed in the fire that burned down the Houses of Parliament in 1834. Copies of this yard were sent to the USA.

Antoine LeCoultre, who established the watchmaking company Jaeger-LeCoultre, invented the 'Millionometer'. This was the first instrument capable of measuring components to the nearest micrometre. The 'Millionometer' revolutionised the watchmaking concept of precision and reliability and it established the metric system as the watch-making industry's worldwide measurement standard.

1845

James Prescott Joule (1784/1858) performed a series of experiment to demonstrate the transformation of energy from one form to another. In the first experiment he placed a paddle wheel in a tank of water, then measured the temperature of the water. After he had cranked the wheel in the water for a measured time, he took the temperature again and found that the temperature of the water rose as he cranked the paddle wheel. When he quantified and compared his observations from many experiments, he discovered that an equal amount of energy was always required to raise the temperature of the water by the same amount. Later he did other experiments to show that he could raise the temperature using other forms of energy. Joule obtained similar results with electrical or magnetic energy as he did with mechanical energy.

Joule's demonstrations showed that different forms of energy can be converted from one form to another. Later, Joule's observations came to be known as the '*Law of conservation of energy*' that states that whenever energy is transferred between two objects, or converted from one form into another, no energy is created and none is destroyed. The total amount of energy involved in the process remains the same.

1847

Many nations in the world used the USA as a model when they wanted to abolish their old, inefficient money currencies and move to decimal currencies. They then used the change to decimal currency as a stepping-stone to full metrication of all of their weights and measures. This was recognised in the USA, in 1847, when the Treasury Secretary of the USA, R. J. Walker wrote:

> *... our decimal system of coinage ... will be adopted, and lead as far as practicable to the introduction of the decimal system of weights and measures ... throughout the world.*

Secretary Walker's words proved true for all nations except for the USA where decimal currency began.

In the UK, Sir John Bowring, a future Governor of Hong Kong, proposed that there should be a new coin, the *Queen*, at ten to the pound, and another new coin, the *Victoria*, at one hundred to the pound. His patriotic arguments obviously won the debate, and the Chancellor of the Exchequer agreed to 'gradually' introduce decimal currency. The *Queen* was renamed the *Florin* and introduced in 1849.

1848

Chile converted to metric measures.

1849

Cuba, Puerto Rico, and Spain converted to metric measures.

The UK made its first attempt to introduce decimal currency when they introduced the Florin, which was carefully labelled '*One Florin – one Tenth of a pound*'.

The Florin was introduced with the aim that '*at the very worst a decimal coin could do no harm*', and that '*the present system could go on if that failed*'. We now know that the Florin, the UK's first decimal coin didn't fail, and the second part of the change was introduced in 1971, once the population had become used to the new coin, having used it for 122 years. These days the Florin is known as ten pence, or by its abbreviation, 10 p.

1850

Norman Robert Pogson (1829/1891), an English astronomer, suggested a classification for the brightness of stars with decimal increments of magnitude. On Pogson's scale a first magnitude star is one hundred times brighter than a sixth magnitude star.

1850s

During the early 1850s, Karl Friedrich Gauss (1777/1855) worked with Wilhelm Eduard Weber (1804/1891) to develop a logical system of fundamental units for electricity and magnetism. Their system was developed and promoted, under the active leadership of James Clerk Maxwell (1831/1879) and William Thomson, later Lord Kelvin (1824/1907) through the British Association for the Advancement of Science (the BAAS). Maxwell and Thomson helped to formulate the requirements for a coherent system of units with base units and derived units.

In particular William Thomson (later Lord Kelvin) played a major part in creating the international system of units used in the world today. He was known to have called the English system of weights and measures 'barbarous.' In a lecture demonstration with a muzzle-loader rifle, confusion between the avoirdupois dram (about 1.8 grams) and the apothecary's dram (about 3.9 grams) caused a student to put into Thomson's muzzle-loader more than twice as much gunpowder as he should have. This could have blown Thomson's head off. However, Thomson's finicky attention to details led him to check the amount with the student before the demonstration. Perhaps this near-death experience with old units stirred Thomson's interest in better methods of measurement.

1851

The British Government awarded the Royal Society its first annual Government Grant of

£1,000 to be distributed for 'private individual scientific research'.

1852

Portugal converted to metric measures.

The height of Mt. Everest was first measured during the '*Great Trigonometrical Survey of India*', and is 8848 metres above sea level. By the way, Sir George Everest who was the first person to record the height and location of Mt. Everest pronounced his name 'eve-rest' and not 'ever-rest'.

Peter Mark Roget (1779/1869) published his famous thesaurus *'to facilitate the expression of ideas and to assist in literary composition*'. Roget's Thesaurus has not been out of print since its original publication. Roget gave credit to '*An Essay Towards a Real Character and a Philosophical Language* (1668) by Bishop John Wilkins, as a source of inspiration for his thesaurus. Wilkins *Essay* included a thesaurus of philosophical words as well as the foundations for the modern metric system.

1853

Colombia and Panama converted to metric measures.

1855

The UK passed the Weights and Measures Act 1855. New standards were made to replace those burned in 1834. Length was based on unofficial standards that had been compared to the Imperial Yard before it was damaged.

1856

The British Parliament recognised the new standard and defined the 'pound avoirdupois' in terms of the mass of a platinum cylinder. This standard became known as the Imperial Standard Pound. They also decided to send copies of the yard and the avoirdupois pound to the United States and to all European countries.

The UK made several copies of the 1855 yard and one of these (Copy No. 11) was sent to the United States together with a copy of the UK pound. When the new set of yard and pound standards from the UK arrived in the USA the bronze bar, known as 'Number 11', was compared to the Troughton scale and it was found to be 0.000 87 inch shorter. Another bar arrived from England for comparison, with the same result. The United States then adopted the new bar as its standard yard to replace the Troughton scale that had arrived in 1815. This 'Number 11' bar then became the legal standard yard for the USA until 1893, when metric system definitions of the inch, foot, and yard were adopted for the USA.

Ecuador converted to metric measures.

1857

Venezuela converted to metric measures.

1859

J. C. Maxwell, after extensive and detailed studies of various sources of light, suggested choosing as a natural standard for length, the wavelength of the yellow spectral line of sodium.

The UK passed the Weights and Measures Act 1859.

Charles Darwin published his book, '*On the Origin of Species*'.

John Taylor wrote *The Great Pyramid: Why Was It Built? & Who Built It?*, in which he argued that measurements such as π (pi) and Φ (Phi) had been deliberately incorporated into the design of the Great Pyramid of Khufu at Giza. This book subsequently had a profound effect on the adoption of the metric system in English speaking nations, especially with the influence of Charles Piazzi Smyth (see 1863 September 30 below).

1860

In the USA, the state of Maine expressed its desire for the adoption of the metric system as the universal system of weights and measures.

1861

The British Association for the Advancement of Science set up an international committee, under the chairmanship of William Thomson, later Lord Kelvin, to choose the best unit for electrical resistance. This committee published its work between 1863 and 1867, and it was this committee who initially proposed definitions for the ohm, the volt and the farad. This committee, that also included James Clerk Maxwell and James Prescott Joule among its members, introduced the concept of a system of units for the first time. They recognised that they could describe electrical activity with only four equations chosen from the work of Ampère, Coulomb, Joule, and Ohm.

The State of Connecticut suggested the adoption of the metric system in the USA. The Secretary of the USA Treasury, Salmon P. Chase, invited Congress to attend … *to the importance of … a uniform nomenclature of weights, measures and coins to the commerce of the world.*

1862

A House of Commons Select Committee in the UK rejected a suggestion that there should be an amalgamation of the decimal system with the English units of measure. This was rejected on the grounds of expense, as it would have cost just as much to do this as it would cost to fully adopt the metric system, but without offering equal gains.

When they finished their deliberations, they released a 'Report of the Select Committee appointed to consider the practicality of adopting a simple and uniform system of weights and measures'. This House of Commons Select Committee unanimously recommended the adoption of metric units for all public administration in the UK. Their report included the line … *no nation which has adopted the metric system has failed to derive the greatest benefit from such adoption, or, after adoption has shown any desire to abandon it.*

Brazil, Mexico, and Uruguay converted to metric measures.

1863

An Act of Congress founded the National Academy of Sciences of the USA. In its first report the President of the Academy wrote: *The discussions in the body of this committee were strongly in favour of the adoption of the French metrical system.*

The USA was represented at two important international weights and measures congresses.

- The International Statistical Congress, meeting in Berlin, declared that uniformity in weights and measures was of the highest importance, particularly for international commerce.
- The Postal Congress, held in Paris, adopted the metric system for international postal services.

Argentina and Sicily converted to metric measures.

Alfred Holbrook wrote '*The Normal: or, Methods of Teaching the Common Branches, Orthoepy, Orthography, Grammar, Geography, Arithmetic and Elocution*. In it he said: *The separatrix (decimal marker) is the most important character used in decimals, and no pains should be spared to impress this on the minds of pupils.*

Italy converted to metric measures.

1863

On July 1, a Bill in the UK for a compulsory change to the metric system was approved by 110 to 75 votes. Speakers argued many of the points we hear today. On the one hand supporters argued its logic and simplicity, savings in time and money, advantages to trade and education. Opponents stressed the undesirability of following the precedent of France and the problems of conversion for the uneducated and disadvantaged. However no specific cut-off dates were proposed, and there was no provision for deprecating the old pre-metric unit names and removing them from laws and statutes.

Sir John Herschell delivered and published a highly influential lecture on September 30 that belittled the '*French Metrical System*' and promoted an alternative of his own devising that was based on the idea that the Earth's quadrant was 500 500 000 inches exactly. This lecture became a major reference in Charles Davies' book, '*The Metric System Considered With Reference To Its Introduction Into The United States*', A. S. Barnes and Company, New York 1871.

To put Sir John Herschell's contribution in context it should be noted that he was a supporter of many ideas in measurement, such as those of no less a personage than the Astronomer Royal for Scotland, Charles Piazzi Smyth.

Smyth was a pupil of Sir John Herschell and, like Herschell, he objected to the use of the metric system and this may account for some of the extraordinary theories he later proposed. I quote from: **http://www.adam.com.au/bstett/PaPyramids13.htm:**

> *Finding that one of the casing stones of the Great Pyramid was approximately 25 inches, equal to (a) cubit, Smyth decided that the inch (one twenty-fifth of a cubit and approximately one 10 millionth part of the Earth's polar radius) must have been the divine unit of length. When it was discovered that the original casing stone was a bit over 25 inches (25.025 in fact), Smyth proposed that the 'Pyramid inch' of 1.001 was the actual divine unit (the British unit presumably got worn down a bit in the pocket of one of the Lost Tribesmen).*
>
> *Of course it did serve to prove that the British measurement system was divinely inspired, which was one in the eye for those nasty French. Smyth used the pyramid inch and various other measurements made at the Great Pyramid to calculate the density of the Earth, its population and, for all we know, the winner of the third at Ascot.*

1864

The British House of Lords debated a Bill to permit the use of metric weights and measures in trade. Parliament passed the Bill and this became the Metric Weights and Measures Act 1864 (27 and 28 Victoria, c. 117). The Act, which contained only three clauses, only applied to trade '*contracts and dealings*'; the Metric Weights and Measures Act did not legalise the use of metric units in day-to-day trade. This Act catalogued all the metric units as they existed at the time and authorized these equivalents:

⊇ 1 metre	= 1 yard 0 feet 3·3708 inches
⊇ 1 kilogram 2 lbs 3oz 4·3830 drams	= 15432·3487 grains
⊇ 1 are	= 119·6033 square yards
⊇ 1 litre	= 1·76077 pints

In the Act other metric weights were catalogued in the appropriate imperial units in cwt, qtr, st, lb, oz, and dr. It was clear from the way the Act was worded that the legal drafters thought that the metric system was much simpler than the old pre-metric measures; and drafted it in a way that, in itself, was a good advertisement for the metric system.

In the USA, Connecticut passed laws that provided for teaching the metric system in all the schools of that State.

In the USA, the state legislature of New Hampshire urged the federal Congress to adopt a decimal system of weights and measures nationally.

Charles Darwin received the Royal Society's Copley Medal, but his book '*On the Origin of Species*' was controversially excluded from the citation. However, a speech given to the Royal Society at the time affirms: *It is with that work that the public ... will naturally recollect the honour.*

Basing his theories on John Taylor's book, *The Great Pyramid* (see 1859 above), Charles Piazzi Smyth published another book based on the idea that the design of the great pyramid of Giza held measuring secrets. In books such as *Our Inheritance in the Great Pyramid* and *The Great Pyramid: Its Secrets and Mysteries Revealed* Smyth claimed to have discovered the exact length of the '*pyramid inch*' used by the pyramid builders. Based on his discovery he then calculated exact sizes for the '*pyramid pint*', the '*sacred cubit*', and for '*pyramid temperatures*'! As Smyth's 'pyramid inch' – according to his calculation – was exactly equal to 1.001 British inches, it followed (at least in Smyth's mind) that the British were the inheritors of this sacred measuring methods incorporated in the structure of the great pyramid at Giza. See Wikipedia web page **http://en.wikipedia.org/wiki/Charles_Piazzi_Smyth#Pyramidological_researches**

> *Smyth claimed, and presumably believed, that the pyramid inch was a God-given measure handed down through the centuries from the time of Israel, and that the architects of the pyramid could only have been directed by the hand of God. To support this Smyth said that, in measuring the pyramid, he found the number of inches in the perimeter of the base equalled one thousand times the number of days in a year, and found a numeric relationship between the height of the pyramid in inches to the distance from Earth to the Sun, measured in statute miles.*

In a recent journal article, *The Battle of the Standards: Great Pyramid Metrology* and *British Identity* 1859-1890 (The Historian, Vol. 65, 2003) Eric Michael Reisenauer writes:

> *The current clash over the euro is something of a distant echo of a controversy from the latter half of the nineteenth century. This dispute centred around the curious and remarkable theory of Great Pyramid metrology (the study of weights and measures). Like its modern counterpart, the debate involved the potential ousting of a traditional British system in favour of a Continental scheme--in this case British imperial weights and measures for the French metric system ....*
>
> *The process of identity formation found in the Great Pyramid theory operated in two ways. One involved the incitement of fear in response to a foreign system seeking to challenge and displace a national tradition--the quintessential Other. While important, however, simply vilifying the Other is not enough. A nation's identity is also validated through its own merits and, if possible, with the sanction of God. The second method did this by asserting and demonstrating an inherent superiority, based in both science and religion, of the traditional system over its potential rival ....*
>
> *Great Pyramid metrology consisted of two distinct but related notions: first, that the Great Pyramid of Egypt at Gizeh was not built as a tomb for the pharaohs but as a storehouse for a divinely-inspired metrological system, and second, that the modern British people, indeed the whole 'Anglo-Saxon race,' had inherited these same standards, virtually unaltered for thousands of years, as a racial patrimony in their own system of weights and measures. Great Pyramid metrologists contended that the base unit used to construct the monument was the Hebrew 'sacred cubit' composed of twenty-five so-called 'pyramid inches.' The pyramid inch, they went on, was virtually identical (save 1/1000th part) to the modern British inch. Britain had therefore inherited a system of weights and measures far older, far more sacred, and, emanating as it did from the mind of God, far more scientific than any other metrological system on earth .... Great Pyramid metrology worked its way into the*

pages of mainstream periodicals, was debated in scientific and religious journals, caused conflict and controversy in British learned societies, inspired the founding of an institute and journal in the United States, attracted the attention of some of the most respected men of the age, and helped delay the introduction of the metric system into the English-speaking world.

1865

USA Senator Charles Sumner, on July 27, in his concluding remarks about the Kassen Act to introduce the metric system into the USA, had this to say before the Senate passed the Bill that became the Metric Act of 1866:

By these enactments, the metric system will be presented to the American people, and will become an approved instrument of commerce. It will not be forced into use, but will be left for the present to its own intrinsic merits. Meanwhile it must be taught in schools. Our arithmetics must explain it. They who have already passed a certain period of life may not adopt it; but the rising generation will embrace it and ever afterward number it among the choicest possessions of an advanced civilization.

Although the Kassen Act began as a measure to make the use of the metric system compulsory, in the course of debate it was amended to become an Act that simply authorized the use of the metric system.

1866

President Andrew Johnson signed The Kassen Act (codified as 15 USC 204 et seq.) into law on July 28. This Act defined the metre in terms of the inch, so 1 metre = 39.37 inches.

Sec. 204. Metric system authorized:

It shall be lawful throughout the United States of America to employ the weights and measures of the metric system; and no contract or dealing, or pleading in any court, shall be deemed invalid or liable to objection because the weights or measures expressed or referred to therein are weights or measures of the metric system.

This law also directed the Secretary of the Treasury to furnish each State with: *one set of standard weights and measures of the metric system*. Further provisions specified that no contract dealing, or court proceeding could be deemed invalid or liable to objection because of the use of metric denominations. They also passed a bill directing the USA Postmaster General to furnish postal balances denominated in grams to all post offices exchanging mail with foreign countries.

The effect of these acts of the USA Congress was to make the use of the metric system legal in the USA, but it was not made obligatory. Brass metric standards were made and distributed to each of the states, and Congress made it practical for the states to follow the federal lead.

1867

The International Geodetic Association, who are concerned with precise measurements of the Earth's surface, recommended the international use of the metric system in geodetic work, and advocated the construction of a new, more precise, prototype metre (differing as little as possible from the Mètre des Archives) to be available for international use, under the supervision of an international bureau.

Prussia converted to metric measures.

1868

Nelson C. Hawks (1841/1929) of California redefined the printer's point to exactly 0.0138 inches by rounding it down to avoid the recurring 8s that occur when you define a printer's *point* as exactly 1/72 of an Imperial inch (1/72 = 0.013 888 888 ...). In doing so Hawks – probably inadvertently – redefined the inch as about 0.9936 Imperial inches

(25.237 44 millimetres instead of about 25.4 millimetres). Hawks printing *point* was now only approximately 1/72 of the Imperial inch used in the USA at that time. The Association of Typefounders of the United States convention in Saratoga officially adopted Hawks' point system as a national standard in 1868.

When computer programmers first encountered all of this old printers jargon they (usually as individuals and within organisations) tried to adapt it to modern computers. Some chose to use the fraction 1/72 and to base their *point* on that value without knowing that this applied to various old pre-metric inches; others chose the imperial inch as their standard and modified the fraction 1/72 a little to make it fit. Needless to say we now have a choice of old pre-metric points that look almost post-modern in their retrofitted construction. Here are the main ones available today – with their approximate value in whole micrometres:

⊇ 1 point (ATA) = 0.3514598 mm = 0.0138366 inch ○ ≈ 351 micrometres

⊇ 1 point (Didot) = 0.3759 mm = 1/72 French Royal inch (27.07 mm) = about 1/68 in. ○ ≈ 376 micrometres

⊇ 1 point (l'Imprimerie nationale, IN) = 0.4 mm ○ = 400 micrometres

⊇ 1 point (Postscript) = 0.3527777778 mm = 1/72 inch ○ ≈ 353 micrometres

⊇ 1 point (TeX) = 0.3514598035 mm = 1/72.27 inch ○ ≈ 351 micrometres

⊇ 1 point (Truchet) = 0.188 mm ○ ≈ 188 micrometres

1870

Just a few months before the fall of the Empire, Napoleon III gave approval for the installation of an astrophysical observatory at the Pavillon de Breteuil, naming Dr Jules Janssen as Director.

During the Franco-Prussian war (1870-71) Paris was besieged. The Pavillon de Breteuil was seriously damaged by shells aimed by the French army at a Prussian battery installed on the hill just above the Pavillon. The stables and outbuildings in the courtyard were completely demolished, but the servants' quarters in the Petit Pavillon just to the south of the main building were untouched.

1871

When the German Empire formed out of several smaller states, it made the metric system compulsory.

Austria adopted the metric system.

Britain almost became a metric country on July 26 when the government lost the Bill to make metric compulsory after two years, by only 82 votes to 77 votes. An argument that might have influenced opponents was a plea that Britain would be:

> *... letting down America and our colonies who had harmonised their systems with those of Britain.*

At that time the American Congress had emulated Britain by allowing contracts that used metric units (see 1866).

Use of the metric system was legalised by an Act of Parliament in Canada.

As a reaction to the acceptance of the metric system for trade by Congress in 1866, the University Convocation of the State of New York published an anti-metric book to counter this trend toward metrication. '*The Metric System Considered With Reference To Its Introduction Into The United States*' by Charles Davies LL. D. was published by A. S. Barnes and Company, New York. As Davies was chairman of the Committee on coins, weights and measures of the University convocation of the State of New York, this book had considerable influence in the USA. This first resolution of their report read:

> *1. Resolved. That the subject of changing our entire system of weights and measures and substituting therefor* [sic] *the Metric System of France, is too grave and too important to be acted upon without a very full and careful examination of all its bearings and all its consequences.*

Probably their major achievement was producing confusion through obfuscation; they promoted the pro-metric support of John Quincy Adams and the anti-metric ideas of John Herschell (see 1863 Sept. 30 above) together with a mish-mash of their own ideas.

1872

The French Government convened an International Commission to meet in Paris. Called the International Commission of the Metre, it became the forerunner of the Conférence Générale des Poids et Mesures (CGPM). Members from the USA attended this meeting, and the Warden of the Standards attended from the UK.

The International Commission of the Metre named the Metre of the Archives as the official definition of the metre and as the standard of length. The delegates were aware that the original measurements made to fix the length of the metre to the quadrant of the Earth in the 1790s had not been exact, so they confirmed that the Metre of the Archives would be the international standard for the world.

This Commission also advocated the construction of international metric standards that were to be kept by an international bureau located near Paris. They arranged for 30 copies to be made of the 'Metre of the Archives' as it embodied the official definition of the metre and the international standard of length. The Commission used the 'Metre of the Archives' as the reference to make the new prototype metres.

1873

A British Association for the Advancement of Science (the BAAS) committee proposed the centimetre, gram, and second as base units for a coherent system of metric units. This became known as the cgs system and it used prefixes from micro to mega. The BAAS committee also proposed a unit of electrical resistance that was later named the ohm.

The American Metrological Society was formed for the purpose of improving systems of weights, measures, and money in the USA.

The term '*horsepower*' was used by James Watt to market his steam engine. It is likely that Watt decided on a figure at 33,000 foot pounds per minute (746 watt) based on the marketing principle of '*under promise and over deliver*' as it was well known at the time that few horses could achieve, let alone maintain, that much effort for very long.

1874

James Clerk Maxwell (1831/1879) and William Thomson (1824/1907) – later Lord Kelvin, further formulated the requirement for a coherent system of units with base units and derived units. In 1874 the British Association for the Advancement of Science (the BAAS) introduced the cgs system, a three dimensional coherent unit system based on centimetres, grams and seconds. The BAAS was also instrumental in having the range of metric prefixes expanded from micro to mega to express submultiples and multiples of units.

Hungary adopted the metric system.

1875

On May 20, a major international conference was held in Paris to discuss standards of measurement. Twenty nations attended but only seventeen nations signed the original ***Convention du Mètre*** (from now on referred to as ***Treaty of the Metre***) during the final session of this conference. The nations that signed were: Argentina, Austria-Hungary, Belgium, Brazil, Denmark, France, Germany, Italy, Peru, Portugal, Russia, Spain, Sweden-Norway, Switzerland, Turkey, the United States of America, and Venezuela.

Here is the official statement from the SI Brochure:

> *Le Bureau international des poids et mesures (the BIPM) a été créé par la Convention du Mètre signée à Paris le 20 mai 1875 par dix-sept États, lors de la dernière séance de la Conférence diplomatique du Mètre.*

The UK, the Netherlands and Hellenic Republic (Greece) attended the conference but refrained from signing.

The UK and Northern Ireland signed the *Treaty of the Metre* in 1884, the Netherlands in 1929, and Greece in 2001.

The UK was not one of the signatories to the original *Treaty of the Metre* because, as the Warden of the Standards declared in 1877:

> *… they could not recommend to Parliament any expenditure connected with the metric system, which is not legalized in this country, nor in support of a permanent institution established in a foreign country for its encouragement. They have consequently declined to take part in the Convention or to contribute to the expenses of the new Metric Bureau, and have directed the Warden of the Standards to decline being appointed a member of the new International Committee or to take part in the direction of the new International Metric Bureau.*

On the Science of Weighing and Measuring by H. W. Chisholm (Warden of the Standards), 1877

Notably the USA was one of the original signatories.

Australia did not attend this first conference and did not sign the international agreement, as they and all other Commonwealth countries were represented by the delegation from the UK. Australia did not sign the *Treaty* in its own right until 1947. See **http://en.wikipedia.org/wiki/Metre_Convention**

As well as founding *Le Bureau international des poids et mesures* (BIPM) and laying down the way in which the activities of the BIPM should be financed and managed, the *Treaty of the Metre* established a permanent organizational structure for member governments to act in common accord on all matters relating to units of measurement.

The *Treaty* gave authority to the:

Conférence Générale des Poids et Mesures (CGPM),

Comité International des Poids et Mesures (CIPM), and the

Bureau International des Poids et Mesures (the BIPM)

to act in matters of world metrology, in particular the demand for measurement standards of ever increasing accuracy, range and diversity, and the need to demonstrate equivalence between national measurement standards.

The BIPM operates under the supervision of the CIPM, which itself comes under the authority of the CGPM. In order to ensure worldwide uniformity in units of measurement, the CIPM acts directly or submits proposals for sanction by the CGPM.

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General Conference on Weights and Measures (CGPM)

The CGPM consists of delegates from all the Member States of the *Treaty of the Metre* and they meet every four years.

The *Treaty of the Metre* established the CGPM as a formal diplomatic organisation responsible for the maintenance of an international system of units in harmony with advances in science and industry. This organization uses the latest technical developments:

- ⊇ to improve the standards system through the choice of the definition;
- ⊇ the method to experimentally realize the definition;
- ⊇ to transfer the standard to practical measurements.

International Committee for Weights and Measures (CIPM)

The CIPM consists of eighteen members each belonging to a different nation and it meets every year. The CIPM reports to the CGPM on the work it has accomplished in the previous four years and indicates the direction it intends to take in the next four. It is responsible for:

- ⊇ discussing and instigating the arrangements required to ensure the propagation and improvement of the International System of Units (SI);
- ⊇ confirming the results of new fundamental metrological determinations and the various scientific resolutions of international scope;
- ⊇ adopting the important decisions concerning the organisation and development of the BIPM.

International Bureau of Weights and Measures (BIPM)

The BIPM is financed jointly by the member states of the *Treaty of the Metre* and operates under the exclusive supervision of the CIPM. The BIPM's task is to provide the basis for a single, coherent system of measurements throughout the world, traceable to the International System of Units (SI). This task takes many forms, from direct dissemination of units (in the case of mass and time), to coordination through international comparisons of national measurement standards (for length, electricity, radiometry and ionising radiation).

The task of the BIPM is to ensure worldwide unification of physical measurements. It is responsible for:

- ⊇ establishing the fundamental standards and scales for measurement of the principal physical quantities and maintaining the international prototypes;
- ⊇ carrying out comparisons of national and international standards;
- ⊇ ensuring the coordination of corresponding measuring techniques;
- ⊇ carrying out and coordinating determinations relating to the fundamental physical constants that are involved in the above-mentioned activities.

The Pavillon de Breteuil was still a wreck from the siege of Paris in 1870 and this was the condition of the buildings when, in 1875, the French government offered the Pavillon de Breteuil to the CIPM for the establishment of the BIPM. At this time the Pavillon de Breteuil was already over two hundred years old. The CIPM agreed to accept the offer of the Pavillon de Breteuil as the site for the BIPM and work began to renovate the Pavillon

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and to construct a new laboratory building to house the instruments and equipment required by the BIPM. Govi from Italy was appointed as the Director – 1875 to 1877.

The 1875 *Treaty of the Metre*, which was modified slightly in 1921, remains the basis of all international agreement on units of measurement.

Following the establishment of the BIPM in France, various nations soon set up their own National Institutions for Measurement. Examples are the Physikalisch Technische Reichsanstalt in Germany (1887), the National Physical Laboratory (NPL) in Britain (1900) and the National Bureau of Standards in the United States (1901).

These National Institutions for Measurement were founded in response to the growing needs from academics, government, and industry for greater accuracy and increased precision for measurements of quantities such as capacity, force, length, mass, pressure, temperature and time.

1876

The original laboratories of the BIPM were begun at the Pavillon de Breteuil in the Parc de Saint-Cloud. Construction took until 1878.

This is an extract from an unknown reviewer of the book *Time Lord: the biography of Sir Sandford Fleming and the Creation of Standard Time* by Clark Blaise.

> *Here, Sandford Fleming enters the scene. At 5:10 p.m. on a bright July day in 1876, in the country station of Bandoran, Ireland, a balding figure with a salt-and-pepper mattress-stuffer of a beard, wearing a gentleman's formal frock coat, alighted from a horse-drawn taxi 25 minutes before the scheduled arrival of the Londonderry train. At 5:35 p.m., nothing came. When Fleming checked, he found that his Irish Railroad Travelers' Guide was mistaken. The train was to arrive at 5:35 a.m. Fleming, chief engineer of the Canadian Pacific Railway, would be a prisoner for the night in Bandoran station. In those hours, a plan took form that would define the Decade of Time.*

This single event motivated Sandford Fleming to rationalise time measurements into zones all around the world measured by 24 hour clocks.

1877

J Pernet from Switzerland, Director of the BIPM from 1877 to 1879.

1878

The UK passed the Weights and Measures Act 1878. The yard was defined as the distance at 62°F between a pair of lines etched in gold plugs set in a bronze bar. This bronze bar was kept at the Standards Department of the Board of Trade in London, together with the Imperial Standard Pound. The metric equivalents of these Imperial pound and yard standards are 0.45359243 kg, and 0.9143992 m respectively. These legal measures were also the standards for all in the British Commonwealth of nations.

The English, during the reign of Queen Victoria, reacted to the world shift toward metrication by having the troy pound declared illegal, and by declaring that commercial trade would be carried out in these quantities: 56lb, 28lb, 14lb, 7lb, 4lb, 2lb, 1lb, 8oz, 4oz, 2oz, 1oz, 1/2oz, 1/4oz, 2dr, 1dr. However this law had effect in some areas but not in others. For example, butchers used the 'butcher's stone' of 8 pounds until the 1950s, and the butcher's stone can be compared to the fruiterer's stone of 14 pounds.

In the USA, the Senate ratified the *Treaty of the Metre* and President Rutherford R. Hayes proclaimed it on September 27. Note that the USA signed the *Treaty of the Metre* in 1875 and ratified it in 1878; signing and ratification are two separate but necessary

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steps in the treaty process. At the same time, various Federal agencies responded unfavourably to the decision of Congress on the use of the metric system in government transactions and purchases. For example, the mint officially adopted the Troy pound as the basis for USA coins. Go to **http://www.nist.gov/pml/pubs/sp447/** to see *Weights and Measures Standards of the United States – A brief history* by Louis E. Barbrow and Lewis V. Judson (1976).

The US House of Representatives resolution of November 6, 1877, read:

> *Resolved, That the heads of the executive departments of the government be, and that they are hereby, requested to report to this House, at as early a date as practicable, what objections, if any, there are to making obligatory in all governmental transactions the metrical system of weights and measures, whose use has been authorized in the United States by act of Congress, and also how long a preliminary notice should be given before such obligatory use can be introduced without detriment to the public service; and that they are also requested to state what objections there are, if any, to making the metrical system obligatory in all transactions between individuals, and what is the earliest date that can be set for the obligatory use of the metrical system throughout the United States.*

J. K. Upton, chief clerk of the Treasury Department, wrote a reply to Congress that was very favourable to metrication. His report began:

> *Sir: In compliance with your verbal request that I present to you, in writing, any suggestions that may occur to me in the matter of the proposed introduction into this country of the metric system of weights and measures, that the same may be transmitted to Congress with your reply to the resolution of the House of Representatives dated November 6, 1877, I have the honour to submit the following:*
>
> *PRESENT STANDARDS.*
>
> *The necessity of uniform standards for measuring distances, weights, capacity, and values among people intimately associated is universally acknowledged, and the Constitution of this country has wisely given to Congress the power to fix these standards. This power has not been freely exercised, and consequently there is no uniform or authoritative standards of measurement throughout the country.*

See **http://lamar.colostate.edu/~hillger/laws/upton-1878-03-06.html** to view the complete report.

1879

O. J. Broch from Norway, Director of the BIPM from 1879 to 1889.

Enthusiasm for the adoption of the metric system was at a high point in the USA. A monthly magazine called "*THE METRIC REFORM*" was produced to achieve this. On an eBay auction in 2010 one article from the 1879 magazine was described as:

> *This wonderful, 8 page, illustrated magazine article presents the arguments for and against the adoption of the metric system of measures to be used in the United States. The article is very well-written and thoroughly covers every aspect of the Conversion Controversy. It seems from the tone of the article that a conversion to the Metric system in America was imminent in 1879 ...*

1880

Most of Europe and South America legally adopted the metric system.

1880s

During the 1880s, the cgs units were applied in many areas of science and engineering.

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In use, the sizes of the coherent cgs units proved to be inconvenient, especially in the fields of electricity and magnetism. The BAAS and the International Electrical Congress approved a mutually coherent set of practical units. Among these units were the ohm for electrical resistance, the volt for electromotive force and the ampere for electric current.

1881

The BAAS recommended definitions for five practical electrical metric units to the First International Electrical Congress in Paris; these were ampere, coulomb, farad, ohm, and volt. The Congress adopted these recommendations.

The USA Congress required that sets of metric standards be distributed to State land grant colleges by the Treasury Department with a Joint Resolution.

1883

The volcano Krakatoa exploded killing an estimated 40 000 people in Indonesia. As this was a global phenomenon, the Royal Society sought observations from the public and letters poured in from many nations, describing the effects of Krakatoa in their regions.

1884

The UK joined the Metric Convention by signing the *Treaty of the Metre*.

Delegates from 27 nations met in Washington, D.C., for a Meridian Conference and agreed on a comprehensive plan for worldwide standard time, developed in the late 1870s by Sir Sandford Fleming, a Canadian railway planner and engineer, The need for a standard time system was particularly felt in the USA and Canada, where extensive railway routes passed through places that differed by several hours in local time.

Fleming's system uses 24 standard meridians of longitude 15° apart, starting with the prime meridian through Greenwich, England. The time is the same in each zone and forms the basis for international legal and scientific time.

Local time varies from Coordinated Universal Time (UTC) by an integral number of hours; minutes and seconds are the same. This is basically the same system that we still all use everyday.

At the Pavillon de Breteuil the laboratory building called the 'Observatoire' was opened.

1887

In Germany they set up a national institution for measurement called the Physikalisch Technische Reichsanstalt.

1889

J R Benoît from France, Director of the BIPM from 1889 to 1915.

The first CGPM approved new international prototypes for the metre and the kilogram and the astronomical second as the unit of time. The metre, kilogram and second now formed a coherent system based on these three units (metre-kilogram-second) that became known as the mks system.

It defined the metre as the distance between two lines on a standard bar of an alloy of platinum with ten percent iridium, measured at the melting point of ice. This International prototype platinum-iridium metre bar had a cross-section shaped like an X to give it more stability.

The London firm Johnson, Matthey & Co made a prototype metre which became the length standard for the whole world when it was adopted as the International Prototype Metre. It was a bar made of a platinum iridium alloy with lines inscribed at each end. The

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metre was defined as the distance between the two graduation lines at 0 °C.

Johnson, Matthey & Co also cast a prototype kilogram that became the international standard for mass. See details at
http://www.npl.co.uk/server.php?show=ConWebDoc.2083

The CGPM formally required that the international prototypes be deposited at the Pavillon de Breteuil.

Each member country of the *Treaty of the Metre* received two copies of the standard with calibration reports relating them to the International Prototype Metre. The copies of the length standard were sent to the national standards laboratories of the member nations. They were accurate, but not identical, replicas of the prototype metre. Each copy was calibrated, by optical comparison, against the prototype for use as a national standard. As signatories of the *Treaty of the Metre*, the USA received a prototype metre and kilogram as measurement standards. A prototype metre and a prototype kilogram were taken to Washington and accepted by President Harrison at the White House; they were then placed in the vault of the Treasury Department. Prototype metre number 27 served as the USA primary standard from 1889 to 1960. During that period it was returned to the BIPM for re-comparison four times so that its length was known in terms of the length of the international prototype. Prototype metre number 27 is now on exhibit in the NIST Museum at Gaithersburg, Maryland.

A serious problem with an International Prototype Metre standard was that there was no method to detect a change in its value due to ageing or misuse. Consequently, it was not possible to state the accuracy or stability of the prototype metre, although calibration uncertainties of the copy metres can be assigned.

In 1889, the year of Joule's death, the BAAS suggested the name *joule* for the work and energy unit to honour the name of James Prescott Joule and his pioneering work on electricity and energy. The BAAS promoted this idea actively and the Second Congress of the International Electrical Conference (IEC) adopted as internationally agreed units the *joule* as a unit of work and energy, the *watt* as a unit of power, and a unit of inductance that was later given the name *henry*.

The UK passed the Weights and Measures Act 1889.

1890

The United States officially received Metre No. 27 and Kilogram No. 20 from the CGPM.

1891

The 1801 mathematical tables of Borda and Delambre had become scarce, and by now greater accuracy was required in astronomy and geodesy. Accordingly the French government issued an eight-figure table containing (besides logarithms of numbers to 120,000) log sines and tangents for every centesimal (hundredth) of the quadrant. This book was called, '*Service geographique de l'armee: Tables des logarithmes a huit decimates, publiees par ordre du ministre de la guerre*', Paris, Imprimerie Nationale, 1891. These tables are still in use where eight-figure accuracy is required.

1892

Albert Michelson (1852/1931), an American physicist, developed an interferometer and used it to determine the length of the International Prototype metre in terms of the cadmium red line wavelength. He had earlier conducted experiments that showed that the red spectral line of natural cadmium was exceptionally coherent. His measurements gave the metre a value of 1,553,164.13 times the wavelength of the red spectral line of cadmium at 760 mm of atmospheric pressure at 15 °C.

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His development of the interferometer inspired Michelson to suggest that light radiation could be used as a standard of length rather than a physical prototype. Using light had many advantages; for example, the international standard of length could be reproduced simultaneously in many places, and the standard would not deteriorate over time.

1893

The Congress of the USA defeated a measure to adopt the metric system.

The prototype metre and a prototype kilogram received by the USA from the CGPM were declared the nation's '*fundamental standards*' by an administrative action of Thomas C. Mendenhall, Superintendent of Weights and Measures. The USA Secretary of the Treasury then sanctioned this decision and the metric prototypes were legally declared to be the '*fundamental standards of length and mass*' for the USA.

From 1893, following the Mendenhall Order, the old measures such as yards and pounds were officially defined in terms of the international metric system by the USA. The USA yard was defined in the Mendenhall Order as:

1 yard = 3600/3937 metre (approximately 0.914 401 83 metre) and

1 inch = 25.400 050 8 millimetres.

This yard is still the basis for the statute foot in the USA. Metre No. 27 served as the standard of length of the USA from 1893 to 1960.

Albert Michelson standardised the measurement of the metre

1894

The USA Congress established an enquiry to study the adoption of the international metric system. The Congress passed a Bill to adopt the metric system, then sent the Bill to a committee – it's still there.

However, in the same year Congress passed a law defining and establishing metric units for electrical measurement. As these units were based on the metric system the USA has used these metric units every day for all electrical purposes since 1894.

Following a Royal Society lecture (1852/1916) agreed with Lord Rayleigh (John William Strutt, 3rd Baron Rayleigh – 1842/1919) that they would research atmospheric gases. In a research tour-de-force they discovered argon, helium, neon, krypton and xenon between 1894 and 1898.

1895

In the UK, a House of Commons Select Committee was appointed to enquire into whether any and what changes in the present system of weights and measures should be adopted. This Select Committee recommended immediate legalisation of metric units for all purposes. They recommended: *That after a lapse of two years the metrical system be rendered compulsory by Act of Parliament,* and that the metric system be taught in elementary schools.

In the USA a resolution to establish a commission to study and report on the feasibility of metric adoption was passed by the House of Representatives. By mistake, the resolution was recorded as requiring the concurrence of the Senate in order to be put into effect. Consequently, the commission was never formally organized.

The Constitution of the State of Utah, in Article X, Section 11, required that '*The Metric System shall be taught in the public schools of the State'*, but this section of the constitution was later repealed.

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1896

The UK passed the Weights and Measures (Metric System) Act, defined as: *An Act to legalise the use of weights and measures of the metric system.*

This legalised the metric system for all purposes, but did not make it compulsory. It standardised the Imperial gallon by defining it in terms of the cubic decimetre, and permitted the use of metric weights and measures in trade. It also required the Board of Trade to include metric denominations among its standards.

1897

The UK legalised the metric system for use in all parts of life.

Vega. H. Schubert published '*Funfstellige Tafeln and Gegentafeln*' in Leipzig. This contained tables for the conversion of angles in sexagesimals (based on 60s) into centesimals (based on the decimal 100s).

1897 August 6

A comprehensive debate in the British Parliament concluded by legalising the use of metric for all purposes in '*An Act to legalize the use of weights and measures of the metric system*, 60 and 61 Victoria, c. 46'. There were no contrary votes. This Act permitted the use of metric weights and measures in all trade, and it required the Board of Trade to include metric denominations among its standards. The UK Imperial yard was measured against the international standard metre and found to be:

1 yard = 0.914 399 metre or *1 inch = 25.399 972 mm*

This is the Act of Parliament that most references indicate to be the beginning of metrication in the UK.

1900

In the UK the National Physical Laboratory (NPL) was begun as a government-funded body managed by fellows of the Royal Society and representatives from industry. Inevitably, there was conflict between scientific research and commercial activity at NPL. The government's civil servants were unsympathetic to fundamental science and were convinced that scientific research should in the long run be financially self-supporting.

1901

Giovanni Giorgi (1871/1950) was an Italian physicist who studied civil engineering at the Institute of Technology in Rome and later taught at the University of Rome. He also held appointments at the universities of Cagliari and Palermo and at the Royal Institute for Higher Mathematics.

Giorgi showed that it was possible to combine the mechanical units of the metre-kilogram-second system with the practical electric units to form a single coherent four-dimensional system. Giorgi pointed out that to do this, we would need a fourth electrical unit, such as the ampere or the ohm, coupled to a rewriting of the basic electromagnetism equations.

In addition to his work on units, Giorgi also contributed to the development of hydroelectric installations, electric distribution networks, and tramways.

Giorgi's system of measurement was first published in 1901 and later it became known as the mksA system because its basic units were the metre, kilogram, second and ampere. In 1960 the General Conference of Weights and Measures endorsed Giorgi's system, after modification, as the *Système International d'Unités (*International System of Units) SI.

The Australian Commonwealth Constitution of 1901, Section 51 (XV) gave the power to

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make laws in respect of weights and measures for the Commonwealth of Australia. During the life of the first Australian Parliament after Federation, the adoption of the metric units of weights and measures was considered, but not adopted, when it was moved that Australia should investigate the adoption of the metric system.

The USA established the National Bureau of Standards.

1902

A Congressional Bill to make the metric system mandatory within the Federal Government of the USA was defeated.

1904

The British House of Lords unanimously voted to make metric compulsory after two years. The Government said they would not obstruct the proposal, but the Bill was never adopted in the House of Commons.

During this debate, an opponent of the metric system, Lord Lansdowne, stated:

> *Considering this question with due attention to the units in actual use and to their relations, the British system of weights and measures is simpler and more uniform than any other system in the world. No traditional system of weights and measures has ever, in fact, been ousted by the metric system.*

In the UK, a White Paper was published that stated that the British colonies (such as Australia, Canada, New Zealand, and South Africa) preferred the metric system to Imperial measures.

The UK passed the Weights and Measures Act 1904.

1905

The National Bureau of Standards of the USA sponsored the first meeting of the National Conference on Weights and Measures.

1906

The length of the metre was re-specified as 1 000 000/0.643 846 96 wavelengths in air of the red line of the cadmium spectrum.

Although the Philippines was under US occupation from 1899 to 1941, the use of the metric system was legalised in 1906, and was actively promoted from 1973.

1907

Two more debates in the British Houses of Parliament failed to have the metric system introduced. One of the major arguments against the metric system was that '*an agricultural labourer would never ask for 0.56825 of a litre of beer*'. The vote against making the metric system compulsory rose from 118 votes to 150 votes.

In the USA, following a refusal by the Committee on Coinage, Weights, and Measures to report favourably on a metric bill, promotional efforts in favour of the metric system died down until the end of World War I.

1908

The Australian Commonwealth Government established the Commonwealth Laboratories as part of the Department of Trade and Customs. They were to provide laboratory services to support excise collection and impose tariffs on imported goods, but their tasks soon also included meat inspection, food analysis and other work.

The Imperial Ambassador of China, after a visit to the International Bureau of Weights

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and Measures at Sevres, on July 29 supported a law in China retaining traditional measures, but redefining these in terms of the units of the metric system. The Paris metre was the central frame of reference and, wherever possible, the decimal system would also be simultaneously introduced.

1911

One of the leading antagonists of metric reform in the UK, Sir Frederick Bramwell, wrote:

> *It is in the interest of British industry to retain British weights and measures because they are the best and most practical. Moreover, industrialists from the metric countries have been encountering difficulties in the Far Eastern market where the British weights and measures had gained earlier acceptance, and this constitutes an advantage that helps our merchants and industrialists in retaining their hold on those regions.*

Frederick Bramwell's view was put more tersely by the Australian journal *The Surveyor*, 1911 January 31:

> *Sir Frederick Bramwell is wont to assert that we enjoy an advantage over foreigners because we can readily grasp their metric measures while they will never be able to understand ours.*

1915

E Guillaume from Switzerland, Director of the BIPM from 1915 to 1936

1916 December 16

A group of businessmen, educators, and consumers met to form the *American Metric Association*. This is now the *United States Metric Association* (USMA). Their purpose was to advocate the adoption of the metric system in USA commerce and education. They held their first meeting as a separate part of the *American Association for the Advancement of Science* (AAAS).

USMA became an affiliate of AAAS and continues this affiliation with AAAS to this day.

The main speaker at the first meeting was Madam Maria Montessori, the Italian originator of the Montessori teaching methods that are still in use throughout the world. She explained how the metric system was used in Italy and stated:

> *... the advantage of the metric system over other systems is shown by its simplicity and the ease which it gives to accomplishing all research work.*

1918

The USA War Department issued a General Order (No. 1) that stated:

> *The metric system has been adopted for use in France for all firing data for artillery and machine guns, in the preparation of operation orders, and in map construction. Artillery and machine gun material for service abroad is being graduated accordingly. Instruction in the metric system will be given to all concerned.*

1921

After a slight revision of the *Treaty of the Metre* by the 6th CGPM in 1921, the scope and responsibilities of the BIPM was extended and it remains the basis for international agreement on all units of measurement. There are now fifty-one Member States, including all the major industrialized countries.

A. Perard began a systematic study of the radiations of cadmium, helium, krypton,

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mercury, neon, thallium, and zinc to find which might prove best for defining lengths. From this time, the Michelson interferometer was in regular use at the BIPM for measuring length.

Albert Einstein was elected to Fellowship of the Royal Society after astronomers had confirmed his general relativity theory to the Royal Society, using observations made during a total eclipse of the Sun of 1919.

1922

In the UK, the National Physical Laboratory made comparisons between the Imperial Standard Yard and the International Metre, which yielded differing values for the inch over the years. The 1922 value of 25.399 956 millimetres per inch was arbitrarily selected for use in calibrating the most precise measuring devices.

1923

Japan commenced conversion to the metric system.

1926

The *Council for Scientific and Industrial Research* (CSIR) was established in Australia. Among its activities related to standards and measurement were: *the testing and standardisation of scientific apparatus and other instruments*.

China became officially metric.

The UK passed the Weights and Measures Act 1926.

1927

The seventh CGPM adjusted the definition of the metre to be the distance, at 0 °C, between the axes of the two central lines marked on the prototype bar of platinum-iridium, this bar being subject to one standard atmosphere of pressure and supported on two cylinders of at least ten millimetres diameter, symmetrically placed in the same horizontal plane at a distance of 571 millimetres from each other.

The CIPM set up the *Comité Consultatif d'Electricité* (CCE) and gave the BIPM the additional responsibility for measurements and standards of electricity. Following this move the Giorgi proposal was thoroughly discussed by the *International Electrotechnical Commission* (IEC), the *International Union of Pure and Applied Physics* (IUPAP), and other international organizations.

Harvard University commissioned an engineer, Arthur Kennelly, to go to Europe to observe the progress of the acceptance of the decimal metric system in those countries that had adopted it. In his report he wrote:

> *Since the year 1800, a wonderful sociological phenomenon has presented itself in Continental Europe. Setting aside Soviet Russia and Turkey, a group of more than thirty countries, with an aggregate population today exceeding three hundred millions, have, one after another, officially adopted the metric system to the abolition of their respective national systems. The change has been voluntary.*

1929

The Pavillon de Breteuil laboratories were enlarged, mostly by extensions to the Observatoire. This was funded by a gift from the Rockefeller Foundation.

1932

James Chadwick published a paper with the Royal Society on his detection of the neutron, and in 1935 he was awarded the Nobel Prize for his discovery. This prepared the

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way for the creation of the atomic bomb.

1935

J. E. Sears, from the UK, proposed that the ampere be selected as the base unit for electricity, and that this be defined in terms of the force per unit length between two long parallel wires. The CCE accepted this proposal unanimously and it was subsequently approved by the CIPM and the CGPM.

1936

A Pérard from France, Director of the BIPM from 1936 to 1951.

Sigmund Freud was elected as a Fellow of the Royal Society.

Official investigations in China revealed:

- 53 different sizes for the *chi* varying from 200 millimetres to 1250 millimetres;
- 36 different *tsin* ranging from 300 grams to 2500 grams; and
- 32 different sizes of the *cheng*, between 500 millilitres and 8 litres.

The UK passed the Weights and Measures Act 1936.

1937

The BIPM was given the responsibility for measurements and standards of photometry.

A bill to fix the standards according to the metric system was considered and recommended by the Committee on Coinage, Weights, and Measures in the USA, but the bill was never enacted.

1938

The Australian Government Cabinet approved the establishment of the National Standards Laboratory (NSL), to be built on a site in the grounds of the University of Sydney.

1939

In the UK the Donaldson Committee proposed a unified National Grid based on the metric system as common framework for Ordnance Survey mapping.

After extensive study of the Giorgi system the CCE proposed the adoption of a system based on the metre, kilogram, second and ampere. This was in contrast to the system based on the centimetre, gram, and second proposed by the BAAS in 1873.

1940

The Australian National Standards Laboratory (NSL) staff began work in the grounds of Sydney University.

1945

General MacArthur, of the USA, as leader of the occupation army urged Japan to actively complete the metrication efforts that they had begun in 1868 and 1923.

1946

The Giorgi proposal was further discussed by the CCE, the *International Electrotechnical Commission* (IEC), and the *International Union of Pure and Applied Physics* (IUPAP) and other international organizations; it was then adopted by the CIPM. The system adopted was a four-dimensional system based on the metre, kilogram, second, and ampere and this became known and widely used as the mksA system.

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The *International Organization for Standardization* (ISO) was founded in Geneva in 1946; on a global scale standardization is coordinated by the ISO. It is concerned with global standardization in all technical and non-technical fields except electrical and electronic engineering, which is the responsibility of the IEC.

The ISO is a specialized international organization that has a membership that includes more than 80 countries, and each member is the national body 'most representative of standardization in its country'. In Australia ISO is represented by *Standards Australia*; in the U by the *British Standards Institution* (BSI), and in the USA by the *American National Standards Institute* (ANSI).

Standardization affects many of the activities of our life each day. It not only affects units of measurement, it is also concerned with specifications for machine parts, materials, surfaces, printing, drawing, processes, tools, methods of testing, and machines.

The ISO establishes international 'technical committees' to investigate and resolve specific issues of standardization and publishes the results as 'International Standards'. Because in most technical fields there are continuous developments the ISO standards are reviewed, and, if necessary, revised, every five years.

1947

Australia became a signatory to the *Treaty of the Metre*. The effect was that metric units were made legal for use in Australia.

1948

The CIPM officially adopted the mksA practical system of absolute electrical units to take effect January 1, 1948. Rapid advances in science and technology in the 19th and 20th centuries had fostered the development of several overlapping systems of units of measurements as scientists improvised to meet the practical needs of their disciplines. In summary the various metric systems developed by these steps were:

⊇ Wilkins' 1668 proposal for a *universal measure*;

⊇ the French metric system of the 1790s;

⊇ the cgs metric system of about 1872, which eventually split into an electrostatic cgs system and a magnetic cgs system;

⊇ the metric system of the *Treaty du Metre* in 1885;

⊇ Giorgi's 1901 mksA metric system proposal;

⊇ formal adoption of☐Giorgi's mksA system in 1948; the other metric systems deprecated (obsolete). It was still sometimes called by its old name, the metre-kilogram-second-ampere, or mksA system.

Following an international inquiry by the BIPM, the CGPM instructed the CIPM:

⊇ to study the establishment of a complete set of rules for units of measurement;

⊇ to find out for this purpose, by official enquiry, the opinion prevailing in scientific, technical and educational circles in all countries;

⊇ to make recommendations on the establishment of a practical system of units of measurement suitable for adoption by all signatories to the *Treaty of the Metre*.

The CGPM laid down general principles for the writing of unit symbols and listed the units that have been assigned special names.

The CGPM ratified three units that had been in use for some time. They were the unit for

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energy – *joule*, the unit for force – *newton* and the unit for power – *watt*. These were all named for eminent English scientists and engineers. The CGPM and the CIPM also formally changed the name 'degree centigrade' to 'degree Celsius' but kept the same symbol: °C.

The mksA system gradually evolved into *The International System of Units* (SI), and this was completed in 1960.

In the USA, the 'Twentieth Yearbook of the National Council of Teachers of Mathematics' was devoted solely to a discussion of the need for, and advantages of using the metric system, particularly for educational purposes.

The Australian *Weights and Measures (National Standards) Act 1948* came into effect. It also provided for the creation of the National Standards Commission (NSC).

1949

The decennial inspection of the London standards for the yard and the pound (carried out in 1947 and 1948) showed that these standards were changing and no longer met the required degree of accuracy. At the same time the same measures in the USA were being referred to the metre and the kilogram in Paris. This meant that British measuring units would begin to diverge substantially from the identically named American yard and pound, causing further difficulties.

1950

The Hodgson Report was published in the UK. After arguing all the points for and against the metric system, it favoured a change to metric.

A new definition of the metre was to be based on the wavelength of Cadmium 114, Mercury 198, or Krypton 86.

Before 1950 the *International Organization for Standardization* (and perhaps the preceding *International Standardizing Association*) had adopted an international inch of 25.4 mm. In 1950, Canada decided to adopt the ISO inch. This meant that the Canadian inch was 25.4 millimetres; the English inch was 25.399 972 millimetres; and the USA inch was 25.400 050 8 millimetres. Australia, New Zealand and South Africa continued to use the UK inch of 25.399 972 millimetres.

The *Australian National Standards Commission* (NSC) was appointed to administer weights and measures legislation for Australia and its territories.

1951

C. Volet from Switzerland, Director of the BIPM from 1951 to 1961.

A British Government White Paper on Weights and Measures was produced by a Board of Trade committee in response to the Hodgson Committee Report published in 1949. This was the 28th Report about the metric system put to Parliament during the preceding 100 years. This very knowledgeable report quite unambiguously supported the introduction of the metric system into the UK. The committee recommended 'an organised change' to the metric system. The report stated that:

> *... the British or Imperial system did not have the standing of the metric system and was not truly international.*
>
> *The United States used British units but also related them to the metre as the standard of reference.*
>
> *The Imperial system was not based on an international convention, nor could it boast an international administrative centre as the metric system did.*

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… that the cost of metrication would be considerable, but the sooner the inevitable reform was introduced the less expensive it would be.

There should be three conditions of going over to the metric system:

1 *an agreement with other members of the Commonwealth binding them to a similar reform simultaneously:*

2 *decimalization of currency and,*

3 *an intensive propaganda-cum-education campaign on behalf of the new system.*

Canada passed an Act of Parliament to redefine old measures according to metric definitions. The pound was defined as 0.45359237 kilogram and the inch was defined as 25.4 millimetres exactly. Canada then led the world with its metric definitions; the rest of the English-speaking world followed Canada's lead by adopting these definitions in 1959.

A British Empire Scientific Conference insisted that the British measures should be redefined in terms of the standard metre in Paris, and the necessary investigations were concluded, establishing the ratios of one yard equal to 0.9143 metre, and one pound equal to 0.453592 kilogram.

1952 November

Contrary to all expectations, the UK Minister of Trade decided against implementing the measurement reform recommended by the Board of Trade the previous year, saying that a metric change was seen as premature.

1953

In a paper to the Royal Society, Francis Crick and James Watson gave details of the structure of DNA, describing it as '*the secret of life*'. This single scientific paper continues to radically change science.

1954

The 10th CGPM in 1954 approved as base units the introduction of the *ampere* for electric current, the *kelvin* for thermodynamic temperature, and the *candela* for luminous intensity. This brought the number of base units to six. These base units measured the following six quantities: length, mass, time, electric current, thermodynamic temperature and luminous intensity. The 10th CGPM also decided to develop an International System of Units based on the metric system.

1955

ICI, the international company originally called Imperial Chemical Industries, decided to '*go metric*' for all of their processes.

1956

The Royal Society established a scientific research base at Halley Bay, Antarctica. In 1985 dramatic losses in the ozone layer were observed and the base remains an important location for climate research.

1957

The Army in the USA issued a regulation establishing metric linear units as the basis for weapons and related equipment. This regulation is still current.

A committee of the Organization of American States proposed that the metric system be adopted throughout North and South America.

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India changed to the metric system in 1957, and then to the International System of Units in 1960.

1959

Following a conference of English speaking nations, the participants agreed to unify their standards of length and mass, and to define them in terms of metric units. Before that, the UK inch measured 25.399 972 mm (see 1897 August 6) while the USA inch was 25.400 050 8 mm. Basically, they adopted the ISO inch of 25.4 mm. The National Bureau of Standards in the USA reported that:

> *As a result of many years of preliminary discussion, the directors of the national standards laboratories of Australia, Canada, New Zealand, South Africa, the UK, and the United States entered into agreement, effective July 1, 1959, whereby uniformity was established for use in the scientific and technical fields. The equivalents 1 yard = 0.9144 metre (whence 1 inch = 25.4 millimetres) ...*

NBS Miscellaneous Publication 247 issued 1963 October, page 20

> *From 1959 July 1, the inch has been standardised as exactly 25.4 mm. Before this agreement, there had never been a standard inch. We could consider 1959, as both the first time there was an international definition of an inch and also as the point when all the different inch-pound standards ceased to exist. As a result, the American yard was shortened and the Imperial yard was lengthened. Since 1959, everywhere in the world, all the old measures such as the inch, the foot, and the yard have now been defined in terms of metres and millimetres. The old pre-metric measures could now be considered as the metric inch, the metric foot, the metric yard, and the metric mile.*

However, in the USA they decided to keep the old Mendenhall foot for some purposes in some states, with the result that the USA now has two different standards for a foot. The yard in the USA (and hence the foot and inch) has been defined in different sizes in 1815, 1856, 1893, and 1959.

The People's Republic of China again decreed metric reform. They proceeded slowly because the terminology of the metric system was alien to the Chinese language and full of sounds that simply did not exist in it. Eventually, the *cheng* was made equal to the litre, the *tsin* to half a kilogram, the *mu* to one-sixteenth of the hectare, and the *chi* actually to one-third of the metre. All of these measures relate to the international definition of a metre.

Old Chinese measures and masses were confiscated by the thousand, melted down, then used in the production of new ones, with considerable saving of raw materials as well as safeguarding the people against potential swindles. Within five months, the operation apparently resulted in there being enough new weights and measures to equip all China; they were made obligatory from 1959, while the former measures of feudal lords were consigned to museums so that the Chinese people could see how others had been cheated in the past. As an example, in the house of a former landowner in Szechuan province the two different measures of capacity that he once used are exhibited. The measure is the *tou*, which should be the equivalent of ten litres, but the two specimens differ by 3.6 litres. The large *tou* was used in collecting dues in kind from the peasants, and the small *tou* when loans of grain were made to them.

1960 October 14

The 11th CGPM 1960, Resolution 12, adopted the name **Système International d'Unités**, with the international abbreviation **SI**.

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The official English translation of the French name is the **International System of Units (SI)** and the official abbreviation of the system, in any language, is **SI**.

The CGPM approved a comprehensive specification for units of measurement that laid down the rules for the prefixes, the derived units, and other matters, for this practical system.

Since then successive meetings of the CGPM and CIPM have added to, and modified as necessary, the original structure of the SI to take into account any relevant scientific advances, as well as the changing needs of SI users.

Just as the original metric system grew out of problems that scientists encountered in dealing with old units, so the International System grew out of the problems that an enlarged scientific community faced in the proliferation of subsystems of the metric system, improvised to serve particular scientific disciplines. At the same time, it was clear that the original 18th century standards were not sufficiently accurate or precise for 20th century science.

The CGPM also redefined and adopted a definition of the International Standard of Length as 1,650,763.73 vacuum wavelengths of light resulting from an unperturbed atomic energy level transition of the krypton isotope having an atomic weight of 86. This change in definition achieved not only an increase in accuracy, but also progress toward the goal of using fundamental physical quantities as standards.

The BIPM was given the additional responsibility for measurements and standards of ionising radiations.

Australia legally adopted the **International System of Units (SI)**. *The Weights and Measures (National Standards) Act 1948* was replaced by the *National Measurement Act 1960*. It defined Australia's units and standards of measurement and the roles of the National Standards Commission and CSIRO in its system of weights and measures.

1961

Greenwich Mean Time (GMT) was changed to Coordinated Universal Time (UTC) by international agreement.

1962

J. Terrien from France, Director of the BIPM from 1962 to 1977.

1963

The 'Weights and Measures Act 1963' was passed in the UK. This defined the basic measures of the *yard* and the *pound* in terms of the *metre* and the *kilogram*. The UK formally redefined the yard as 0.9144 metres and the pound as 0.453 592 37 kilograms. Since then the old English measures have all legally depended on the SI standards, metre and kilogram. Many of the old Imperial measures were abolished. Examples are: drachm, scruple, minim, chaldron, quarter, rod, pole, perch.

The British Standards Institution produced a survey that indicated a significant majority of industry in the UK favoured metrication.

1964

Extensions of the activities of the BIPM required the construction of additional buildings. Two laboratory buildings were constructed at Pavillon de Breteuil for work on ionising radiation. These also required an extension to the site, bringing it to about 40 000 m^2.

Helium-Neon stabilized laser wavelengths were coming into use as length standards. Although the laser wavelength was generally accepted as a secondary standard, its

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widening use was mainly based on its remarkable coherence. Long distances, that would be impossible to measure with atomic light sources, could be readily measured with laser interferometry.

In the USA, the National Bureau of Standards (NBS) made The International System of Units (SI) its standard '*except when the use of these units would obviously impair communication or reduce the usefulness of a report*'.

Dorothy Hodgkin, supported by the Royal Society, was the UK's only female Nobel Prize winner, receiving it for her x-ray crystallography work on penicillin and vitamin B12.

1965

At the request of industry in the UK, the president of the Board of Trade finally announced that the metric system would be adopted in the UK. The Government announced financial support for metricating the UK with a target for completion within 10 years. The UK Board of Trade estimated that the cost would run into millions and they were aware that this was immeasurably more than if the step had been taken in 1862, 1904 or 1911.

The governing body of the National Physical Laboratory (NPL) in the UK was dismissed, the long-term link with the Royal Society was ended, and the NPL became part of the Ministry of Technology.

Many of the Commonwealth and other countries decided to follow Britain's example (New Zealand and South Africa in 1967, Australia and Canada in 1970).

The Australian National Standards Commission was given responsibility to '*pattern approve*' measuring instruments used for trade.

1968

Following a report by the UK Standing Committee on Metrication, '*Change to the Metric System in the United Kingdom*', the Metrication Board was established in the UK. However, the Metrication Board was restricted to only providing metric information; it was not permitted to promote the benefits of the metric system. Curiously, the formation of the UK Metrication Board took place in the 300^{th} anniversary year of John Wilkins first design for a '*universal measure*' in 1668 (see above).

The USA Congress passed the '*Metric Study Act*' and President Lyndon B. Johnson signed this act into law. This study was to place particular emphasis on the feasibility of the USA adopting SI as its metric system.

Following the enactment of this law, the Secretary of Commerce authorised the National Bureau of Standards (NBS) to undertake a three year study to determine the impact of increasing metric use on the USA. Specifically the NBS was '*to determine advantages and disadvantages of increased use of metric system in the United States*.'

The report of the 45-member advisory panel concluded that the USA would eventually join the rest of the world in the use of the metric system of measurement. This conclusion was based on extensive consultation with hundreds of business organizations, consumers, labour unions, manufacturers, and local and state government officials. The report of this study was produced in 1971, and it recommended that the USA adopt a ten year plan for metrication. The 1971 Report to the Congress (see below) was entitled:

A Metric America, a decision whose time has come.

1969

The international status of the BIPM with regard to the French Government was formalized in an agreement signed between the CIPM and the French government. The

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site of the Pavillon de Breteuil is now considered international territory and the BIPM has all the rights and privileges accorded to an intergovernmental organization. No doubt the Baron de Breteuil, as an international diplomat with an interest in science, would be pleased to know that the Pavillon that bears his name has become the permanent home of the BIPM, a truly international scientific organisation.

The New Zealand Government appointed a Metric Advisory Board with Ian D. Stevenson as Chairman. The Board set up 14 Sector Committees, 24 Divisional Committees, and a number of industrial committees with liaison to the Board. In order to give metrication a human face, Ian Stevenson found a baby girl who he named 'Miss Metric'. He published pictures of the baby, together with her body measurements given in metric system units, in the newspapers. The New Zealand papers followed her development through her school years, again with metric data.

The UK Government established the Metrication Board in 1969 after the Confederation of British Industry and the British Standards Institution announced that industry was in favour of metrication. The goal of the UK Metrication Board was to help industry go metric in an orderly fashion; the Board was to educate the public and business, and to encourage the adoption of the metric system. For example, the apothecaries system was deprecated (obsolete) for dispensing medicines and it was replaced by the metric system. A target date of 1975 was set, by which time it was anticipated that the UK would be substantially metric. On July 21, '*The Times*' in London published a special report on Decimal Currency and Metrication. This paragraph is from the article:

> *The change to the metric system is more profound and complex than decimalizing the coinage. There is no simple way of saying that such-and-such will happen: it certainly cannot be done by diktat. The impact of the change will be spread widely through the economy and widely through time. Nevertheless, the Government has set a target date – the end of 1975.*

1970

Ordnance Survey maps began to include metric elevations during re-surveying of UK.

The Australian Government passed the Metric Conversion Act with the aim of making the metric system the sole system of legal measurements in Australia. The Metric Conversion Board was established and Australia commenced its rapid change to metric units for almost all activities.

The Canadian government also decided to 'Go metric' by issuing a statement that said that metrication is a definite objective of Canadian policy. Government parties supported the Canadian White Paper on Metric Conversion unanimously.

1971

The 10th CGPM (1954, Resolution 6) and the 14th CGPM (1971, Resolution 3) adopted as base units of this practical system of units the units of the following seven quantities: length, mass, time, electric current, thermodynamic temperature, amount of substance, and luminous intensity. Adding the mole as the base unit for amount of substance, bringing the total number of base units to seven, completed the current version of The International System of Units (SI).

The USA National Bureau of Standards Metric Study presented its 13-volume USA Metric Study Report; the summary was entitled '*A Metric America – A Decision Whose Time Has Come*'. The report concluded that the USA should deliberately and carefully 'go metric' through a coordinated national program, and should establish a target date 10 years ahead, by which time the USA would be predominantly metric. Here is a copy of the covering letter of that report:

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THE HONOURABLE PRESIDENT OF THE SENATE,
THE HONOURABLE SPEAKER OF THE HOUSE OF REPRESENTATIVES
SIRS:

I have the honour to transmit to you the Report on the U.S. Metric Study, which was conducted by the National Bureau of Standards of the Department of Commerce. Thousands of individuals, firms and organized groups, representative of our society, participated in the Study. After weighing the extensive evidence presented by these participants, this report concludes that the United States should change to the metric system through a coordinated national program, I agree with this conclusion, and therefore recommend:

- *That the United States change to the International Metric System deliberately and carefully;*
- *That this be done through a coordinated national program;*
- *That the Congress assign the responsibility for guiding the change, and anticipating the kinds of special problems described in the report, to a central coordinating body responsive to all sectors of our society;*
- *That within this guiding framework, detailed plans and timetables be worked out by these sectors themselves;*
- *That early priority be given to educating every American school child and the public at large to think in metric terms;*
- *That immediate steps be taken by the Congress to foster U.S. participation in international standards activities;*
- *That in order to encourage efficiency and minimize the overall costs to society, the general rule should be that any changeover costs shall "lie where they fall";*
- *That the Congress, after deciding on a plan for the nation, establish a target date ten years ahead, by which time the U.S. will have become predominantly, though not exclusively, metric;*
- *That there be a firm government commitment to this goal.*

The Department of Commerce stands ready to provide whatever further assistance the Congress may require in working out a national plan and putting it into effect.

Respectfully submitted,
Maurice H. Stans
Secretary of Commerce

The Australian Wool Industry changed the international trade for wool to metric units. Initially this meant wool was sold in kilograms at auction, but during the 1971/72 season, objective measurement of wool was introduced using micrometres for wool fibre diameters and millimetres for wool fibre lengths.

British decimal currency was introduced smoothly and quickly into the UK on February 15 1971; pounds, shillings, and pence were replaced with decimal money – 100 pennies to one pound.

The Canadian Metric Commission was established with more than 100 different sector committees.

1972

The Senate of the USA unanimously passed the *Metric Conversion Act of 1972*.

In the UK, another government 'White Paper' on metrication advocated a gradual rather than a compulsory change to the metric system. Geoffrey Howe became the responsible

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Minister for metric conversion in the new British government. The transition to metrication and the role of the Board were given positive support and encouragement. There was at this time a wealth of information within the Department of Trade to show that a clear retail cut-off date was both desirable and inevitable exactly as 19th Century parliamentarians had foreseen. However, no cut-off dates were set. This proved particularly relevant to retailers of 'loose weight' products over the next 35 years.

Australian grains, dairy products, and eggs used metric measurements for trade. Some primary schools began to teach the old 1850s cgs system alongside the old units.

1973

The International System of Units (SI) began to be taught in Australian secondary schools. Sadly, this was done alongside the teaching of cgs, mksA, and other old metric units, and had the net effect of making the teaching of measurement more complex than it needed to be.

Tobacco, sugar, and peanuts were sold in grams and kilograms in Australia. The leather tanning industry began to use some metric units in parallel with their old units.

In the UK, the European Communities Act involved giving responsibility for weights and measures legislation to the European Economic Community (EEC). This was the inevitable result of the UK decision to join the EEC, and by joining the EEC the UK government re-affirmed its commitment to adopt the metric system.

The *United States Metric Association* (USMA) and other professional groups combined to convene a National Metric Conference. The National Metric Conference was the largest ever held with 1700 registrants. At this conference, the American National Metric Council (ANMC) was formed to plan and coordinate the metric system implementation by USA industry.

The Philippines began active promotion of the metric system. The Philippines first legalised the use of the metric system in 1906.

1974

By the end of 1974, most industries in Australia had converted to metric, e.g. building industry, timber, paper and printing industry, agricultural and veterinary chemicals, meteorological services, photography, postal and communication charges, road transport and travel, textile industry, gas and electricity services, land and surveying, sport and recreation, water and sewerage, mining and metallurgy, rubber, chemicals and petroleum derivatives, fabricated metal products, automotive engineering, all beverages apart from spirits, ship building, aeronautical engineering.

The metric system began to be taught in schools in the UK and items in metric packaging began to appear in UK shops.

The USA Education Amendments encouraged educational institutions to prepare students to use the metric system of measurement as part of their educational program. This was the first official legislation concerning conversion to the metric system as part of Public Law 93-380, to extend and amend the Elementary and Secondary Education Act of 1965. Under section 403 of this Act entitled, '*Education for the Use of the Metric System of Measurement*' it states:

> *... the metric system of measurement will have increased use in the United States, and as such, the metric system will become the dominant system of weights and measures in the United States.*

This legislative change subsequently had little support in educational institutions.

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The House of Representatives in the USA (in a 240 to 153 vote) also defeated a motion to suspend the rules to consider metric conversion legislation (HR 11035) without any amendments being attached.

1975

By 1975, many Australian industries had changed to metric measures. These included building, timber, paper, agricultural and veterinary chemicals (but not human), meteorological services, postal charges, road transport and travel, gas charges, surveying, sport and recreation, water and sewerage, mining and metallurgy (except gold and tin), rubber, chemicals and petroleum, fabricated metal products, automotive engineering, beverages, ship building and aeronautical engineering.

In the USA, Congress passed the Metric Conversion Act of 1975. The Act established the USA Metric Board 'to coordinate and plan the increasing use of the metric system in the United States' and 'to coordinate and plan the increasing use and voluntary conversion to the metric system'. While one aim of the Metric Conversion Act' was 't*o foster voluntary conversion*' to the metric system, there was no '*ten year plan*' as recommended in the 1971 report, '*A Metric America – A Decision Whose Time Has Come*'. This Act had little apparent effect without a specified time period and it took only two lobbyists and political insiders, Republican Lyn Nofziger and Democrat Frank Mankiewicz, to sabotage the metrication effort in 1981 (see below).

Metric product labelling began in Canada. Canadian weather forecasters began to use degrees Celsius and to report rainfall and snowfall in metric units. Canadian schools began to teach using metric only.

1976

On 5 May 1976 the Australian Minister for Trade and Industry and the Minister for Labour issued a press release that said:

> *Building and construction, transportation, and a wide range of manufacturing and processing industries had substantially completed the metric changeover, and all other industries were well on the way. The Australian Government would ensure that the changeover was made thoroughly and well by outlawing the old system of measurements as early as it could efficiently do so.*

In Australia, by the end of 1976, all packaged goods were required to be labelled in metric sizes, and the following were also converted to metric: air transport industry, food energy, petrol pumps, machine tools, electronic and electrical engineering appliance manufacturing.

The UK passed another *Weights and Measures Act 1976* gradually abolishing various old measuring units as well as redefining their measuring standards using metric standards. Apothecaries' measures were now gone, but they kept the Troy ounce after redefining it in grams.

From 1 April 1976, Canadian wind speed, visibility, and atmospheric pressure were in metric units, with air pressure in kilopascals.

Members were appointed to the Metric Board of the USA.

1977

In Australia, verification of non-metric weighing or measuring appliances used in trading ceased. Products sold by length or area, such as textile products and floor coverings, were to be sold in metres, and all pricing and advertising was to be in metric.

The Department of Prices and Consumer Protection presented a 'Metrication Report' to

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the UK Parliament.

All new cars in Canada were required to have metric speedometers and odometers and all road signs were marked in metric

1978

P Giacomo from France, Director of the BIPM from 1978 to 1988,

SI became the legal system of units in the nations of the European Union.

The necessary order for cut-off dates, drafted by the UK Board of Trade, was agreed by a huge range of retail trade, industry, engineering, consumer, trade union, elderly person, sporting and educational organisations, and the overwhelming number of parliamentarians. However, the initiative was in the hands of Secretary of State for Trade, Roy Hattersley and a General Election was expected in 1979. He chose not to test the opinion of the Parliament and withdrew the draft order. Labour lost the election. Margaret Thatcher became Prime Minister and appointed Sally Oppenheim, a long time critic of the metric program, as junior Minister of Consumer Affairs at the Department of Trade and Industry with metrication as part of her portfolio.

The Australian National Measurement Laboratory (NML), formerly the National Standards Laboratory, moved to Lindfield, a suburb of Sydney.

1979

Despite the fact that many sectors of UK industry had already changed to metric units and many others were preparing to do so, the newly elected Conservative government abolished the Metrication Board.

In the USA, the Treasury Department's Bureau of Alcohol, Tobacco, and Firearms required wine producers and importers to switch to metric bottles in standard, litre and millilitre sizes.

1980

The iodine stabilized Helium-Neon laser wavelength was accepted by CGPM as a length standard. At the time, it had a wavelength uncertainty of 1 part in 10^{10}. This uncertainty is equivalent to an accuracy of 1 mm in 10 000 km.

Recognising that most Commonwealth countries had completed their metric conversion and that the UK lagged behind significantly, the British Parliament approved a Statutory instrument (1980/1070) which began the progressive phasing out of the Imperial system by withdrawing authorisation of a substantial number of units, such as the British thermal unit (Btu), the cran, the furlong, the horsepower, the hundredweight, the ton, and the Fahrenheit degree.

The 'Final Report of the UK Metrication Board' was presented to Parliament. See: **http://www.metric.org.uk/Docs/DTI/met1980.pdf** for a full copy and for an historical perspective by the last Director of the UK Metrication Board see:

However, increased production costs from continuing to work in dual systems of measuring were still an issue. A report to the Confederation of British Industry (CBI) in 1980 estimated 'the extra cost of continuing to work in dual systems of measuring was around £5 000 million every year'. For companies on which the survey was based, increased production costs were equal to 9% of the companies' gross profit and 14% of their net profit. To put this into perspective: in 1980 £5 000 million was roughly half the cost of the entire UK National Health Service; in today's currency 5 000 M£ is equivalent to about 12 000 M£; and the net saving from 1980 to 2006 is about 110 000 M£ – plus compounding interest for ever year since 1980.

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The USA Treasury Department's Bureau of Alcohol, Tobacco, and Firearms required distilled spirits bottles to conform to standard metric sizes in litres and millilitres. As the USA changed to metric bottle sizes they were able to rationalise the number of sizes from 38 different sizes to 6 different bottles.

Canadian fabrics began to be sold by the metre.

1981

The Australian Metric Conversion Board was dissolved.

Canadian automotive fuels began to be sold in litres.

In a Washington Post 'remembrance' of the late Reagan Press Secretary and leading Republican Lyn Nofziger, long-time political rival Democrat Frank Mankiewicz claims that the two of them had secretly worked together to kill the metric system in the United States. Mankiewicz wrote in the Washington Post (**http://www.washingtonpost.com/wp-dyn/content/article/2006/03/28/AR2006032802142.html**)

> *... during that first year of Reagan's presidency, I sent Lyn another copy of a column I had written a few years before, attacking and satirizing the attempt by some organized do-gooders to inflict the metric system on Americans, a view of mine Lyn had enthusiastically endorsed. So, in 1981, when I reminded him that a commission actually existed to further the adoption of the metric system and the damage we both felt this could wreak on our country, Lyn went to work with material provided by each of us. He was able, he told me, to prevail on the president to dissolve the commission and make sure that, at least in the Reagan presidency, there would be no further effort to sell metric.*
>
> *It was a signal victory, but one which we recognized would have to be shared only between the two of us, lest public opinion once again began to head toward metrification.*

1982

President Ronald Reagan disbanded the USA Metric Board and cancelled its funding. Responsibility for metric coordination was transferred to the Office of Metric Programs in the Department of Commerce.

1983

The CGPM again redefined the metre, this time as the length of the path travelled by light in vacuum during a time interval of 1/299 792 458 of a second (17^{th} CGPM, Resolution 1). This was based on the speed of light as c = 299 792 458 m/s exactly. As always when the CGPM changed this definition, the goal was not only to improve the precision of the definition, but also to change its actual length as little as possible. The unit of length is one of the seven base units in SI and this is its current definition.

The modern length standard has now evolved over 200 years and it can now be continually improved without the necessity of changing its definition. The CGPM recognised that advances in the technology of lasers would lead to a new concept for the length standard definition and chose to base this standard on the speed of light. Because this was not based on any particular radiation, it opened the way to improvements in the precision with which the metre can be realised without changing its length.

The BIPM stipulated that the metre can be realised by any of the following three methods.

- The metre can be realized by a direct measurement of the distance that light travels in a vacuum in a measured time interval. Although this method follows directly from the definition, it cannot achieve the accuracy possible with the other two and so it is not used for practical purposes.

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- The metre can be realized by a direct measurement of the frequency of radiation and calculating the wavelength in a vacuum. This method measures laser frequencies in terms of the caesium clock. A complicated series of measurements is required because different regions of the electromagnetic spectrum require different measurement technologies. The accuracy of this method is about 7.2 parts in 10^{12}, or you could think of this as being within 0.4 millimetres when measuring the distance between the Earth and the Moon (385 000 km).
- The metre can be realized by means of one of the radiations from a list provided by the BIPM. This is the most practical method and establishes length standards by using the frequencies of certain stabilized lasers whose performance has been carefully measured. In this way, a laboratory standard of known frequency can be constructed using the specifications and operating conditions provided by the BIPM. A common laser used for this is the iodine stabilized HeNe laser operating at 633 nm. It is used because it is convenient to operate; it is accurate to 2.5 parts in 10^{12}; and it can be readily used to calibrate commercial measuring systems. This level of accuracy is equivalent to being within 1 millimetre in 40 megametres, or put another way, it is as accurate as measuring from the equator to the North Pole to within a single millimetre.

The second (which is equivalent to 9 192 631 770 oscillations of the ^{133}Cs atom) is determined to an uncertainty of 1 part in 10^{14} by the use of a Caesium clock. This is the equivalent accuracy to a clock that is out by one second every 3 000 000 years.

'The Gimli Glider' made national news as Canada's most notorious metric conversion mix-up. See **http://www.wadenelson.com/gimli.html** for Wade H Nelson's article.

1984

A new building was constructed and opened at Pavillon de Breteuil for work on lasers.

In Australia, responsibility for the completion of metrication was transferred to the National Standards Commission.

In Canada, the deadline for full metric conversion of retail sales passed but no provision was made to enforce this law. The Ontario Court of Appeal reconfirmed that the litre must be used for all fuel sales. However, Consumer and Corporate Affairs, the ministry responsible for *Metric Commission Canada*, announced that it would ignore the recent court ruling in Ontario and would not prosecute people who violated metric laws.

1985

The UK passed the Weights and Measures Act 1985. The UK Parliament reaffirmed the legal status of the metric definitions of the pound and the yard in the Weights and Measures Act of 1985. This Act also defined the 'gallon' in terms of the 'litre'. This meant that all the measures had now been defined in terms of metric units. They also discarded the curie, the rem and the rad in favour of the bequerel, the sievert and the gray respectively and discarded all of the apothecaries' and troy weights and measures; these are no longer legally recognised in the UK.

In January, Michel Côté, the Canadian Minister for Consumer and Corporate Affairs, announced that regulations requiring use of metric measurements would be revoked and replaced by new provisions. In March, the Ministry for Consumer and Corporate Affairs disbanded *Metric Commission Canada* and replaced it with a small *Metric Office* in the Bureau of Policy Co-ordination within Industry Canada. And then in October, the Canadian *Metric Office* became the *Canadian Measurement Information Division* and their staff was significantly decreased.

Dramatic losses in the ozone layer were observed from the Royal Society established research base at Halley Bay in Antarctica.

1986

The Canadian deadline for full metric conversion of advertising and signage for individually weighed items passed without any attempt at enforcing these laws.

1987

Australian real estate trading conducted using metric measures.

1988

British scientist Dr Terry Quinn from U.K. appointed 10th Director of the BIPM. Like most of the other Directors, he lived in the Pavillon de Breg136

teuil in the Parc de Saint-Cloud. The BIPM was given the additional responsibility for measurements and standards of time scales and a new building was constructed and opened at the Pavillon de Breteuil to serve as a new library and offices.

In the USA, the Omnibus Trade and Competitiveness Act amended and strengthened the Metric Conversion Act of 1975, designating the SI metric system as the preferred measurement system, and requiring each federal agency to be metric by the end of 1992. This Act also changed the National Bureau of Standards to the *National Institute of Standards and Technology* (NIST).

The Australian government passed laws that withdrew the remaining Imperial units from general legal use. However, some were listed in the regulations as temporary exceptions – these are still in use in 2008.

The *Canadian Measurement Information Division* was abolished. No further official effort has been made to complete metrication in Canada.

1989

The European Union (EU) issued Directives on Weights and Measures. This declared the metric system as the official measurement system of all member countries. The main effects of the EU Directives were to mandate the use of metric units for all pre-packed goods by the end of 1994, and for all bulk goods to be priced in terms of metric units by the end of 1999. Some politicians felt that this directive placed considerable pressure on the UK, so the UK government began negotiations with the EEC to delay implementation of aspects of the metric system.

A Canadian opinion poll found that 79% of the population think in degrees Celsius.

Sir Tim Berners-Lee proposed a global hypertext computer language that resulted in the creation of the World Wide Web.

1991

President George Bush signed Executive Order 12770, 'Metric Usage in Federal Government Programs', directing federal departments and agencies to use the metric system in all its dealings, including construction and public works.

1992

The summary of Australia's metrication experience was published as: *Metrication in Australia* by Kevin Wilks, which provides a valuable historical record of the Australian metrication process. This is an extract from its foreword:

> *Metrication effectively began in Australia in 1966 with the successful conversion to decimal currency under the auspices of the Decimal Currency Board. The conversion*

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of measurements -metrication -commenced subsequently in 1971 under the direction of the Metric Conversion Board and actively proceeded until the Board was disbanded in 1981. The process was a most significant event in Australia's integration with the modernising world.

Metrication is still in its early stages in the USA, which looks to Australia as an example and a model of how the process can be carried out. Because of the USA's strong cultural influence upon us, Australia's conversion can never be 100% until that nation has also converted.

One can't help being impressed by the magnitude of the task, by how much thought, planning and effort went into bringing it about, and by how many members of the general community participated in it. The change affected all Australians in both their private and professional lives and has been recognised as one of the great reforms of our time.

1994

In the USA, the 'Fair Packaging and Labelling Act' was amended to require the use of dual units (inch-pound and metric) on all consumer products.

1995 October 1

The Ministry for Education in Victoria suggested that the 1947 mksA should be used as the standard measures for use in primary schools.

The UK government passed legislation, making the 1989 European Union (EU) Directives on Weights and Measures legal in the UK. This meant that 'for economic, public health, public safety, and administrative purposes', only the metric system units have been allowed. This meant that all packaged goods in the UK were required to be labelled in metric units. However, the following were allowed as exceptions:

Some had a time limit to 1999 December 31. These were:

- pounds and ounces for weighing of goods sold in bulk;
- pints and fluid ounces for alcoholic beverages such as beer and cider, water, lemonades and fruit juices in returnable containers;
- therms for gas supply;
- fathoms and nautical miles for marine navigation.

And some have no time limit. These are:

- statue miles, yards, feet and inches for road traffic signs and related measurements of speed and distance;
- pints for dispensing draught beer and cider, and for milk in returnable containers;
- acres for land registration purposes and surveyors' measurements;
- troy ounces for transactions in gold and other precious metals.

1996

All four Canadian Stock Exchanges began trading in decimal currency. They were the first exchanges in North America to abandon the old 'pieces-of-eight' trading system and to welcome the new (1792) decimal system. The old tradition of trading stocks in increments of one-eighth of a dollar, or 12.5 cents, dated back to when the Spanish peso could be divided into 'pieces of eight' for the purpose of giving change.

From 1996, all temperature observations from the National Weather Service of the USA were reported in degrees Celsius.

The USA Congress passed the 'Savings in Construction Act' that gave 'certain elements' in the construction industry the ability not to use metric units in 'certain instances'.

1997

At 1997 December 31, there were forty-eight nations that were members of the *Treaty of the Metre*. They were:

Argentina, Australia, Austria, Belgium, United States of Brazil, Bulgaria, Cameroon, Canada, Chile, China, Czech Republic, Denmark, Dominican Republic, Egypt, Finland, France, Germany, Hungary, India, Indonesia, Iran (Islamic Rep. of), Ireland, Israel, Italy, Japan, Korea (Dem. People's Rep. of), Korea (Rep. of), Mexico, Netherlands, New Zealand, Norway, Pakistan, Poland, Portugal, Romania, Russian Federation, Singapore, Slovakia, South Africa, Spain, Sweden, Switzerland, Thailand, Turkey, UK, United States of America, Uruguay, Venezuela.

In Australia, the National Analytical Reference Laboratory was established as part of the Australian Government Analytical laboratory (AGAL) as a response to the need for chemical metrology standards and international activity in this field.

1998

The USA congress amended the 1988 Omnibus Trade and Competitiveness Act to make compliance voluntary.

1999 September 23

The Mars Climate Orbiter spacecraft crashed onto the surface of Mars when USA Customary measures were used instead of metric units. This happened because the navigation software was programmed by the Jet Propulsion Laboratory to accept metric data in newton seconds but the maker of the spacecraft Lockheed Martin Astronautics provided the information in pound-force seconds. This meant that the retarding force was only about a quarter of what was needed. This cost about 1200 million dollars.

In Australia, the Australian National Standards Commission was given responsibility for pattern approval and compliance testing of electricity, gas and water meters.

2000

In the USA, the automotive, pharmacy, earth moving machinery, refrigeration, electronics hardware, IEEE standards, University and Olympic sports, military training and operations, highway construction, federal building construction, nutritionists and many others have changed to a metric system, or to SI. However, this was often '*hidden metric*' in that the fact that they operated in metric units was hidden from their suppliers and their customers.

SI had now become a dominant force in international trade. Although where international trade is concerned you need more than just the International System of Units, you also need to use international standards, such as those provided by the International Organization for Standardization (ISO), individual product standards, and preferred sizes that are accepted by your customers all around the world. It is now essential that goods, manufactured anywhere in the world, are built to these specifications so that all manufacturers can be competitive in the international marketplace.

In the UK, 'loose goods' were required to be priced, weighed and measured in metric units. However, the law also provided for 'supplementary indications' (that is prices for old pounds, feet, and inches); these were to be permitted for 10 years, until 2009.

In the USA, Tennessee adopted the Uniform Packaging and Labelling Regulations, based on the Fair Packaging and Labelling Act of 1994.

2001

The New York Stock Exchange (NYSE) changed to decimal trading. Prior to this they had used the 'pieces-of-eight' that they originally adopted in 1792.

Sir Tim Berners-Lee was elected a Fellow of the Royal Society for his proposal of a global hypertext project (see 1989 above) that resulted in the creation of the World Wide Web.

2002

The CIPM recommended that the 1983 definition be restricted to:

> *lengths which are sufficiently short for the effects predicted by general relativity to be negligible with respect to the uncertainties of realisation.*

In a speech to the United Nations, President George W Bush of the USA, referred to 'litres of anthrax,' 'metric tons' and '150 kilometre range missiles.'

2004 January 1

Professor Andrew Wallard was appointed Director of the BIPM. Before this, he had been Deputy Director and Chief Metrologist of the National Physical Laboratory in the UK. He replaced Dr Terry Quinn CBE FRS, who had been Director of the BIPM since 1988. Upon his retirement, Dr Quinn became Director Emeritus of the BIPM.

The Australian National Measurement Institute (NMI) was established by uniting the Australian Government Analytical Laboratory (AGAL), National Measurement Laboratory (NML), and the National Standards Commission (NSC). It advises the Australian and state governments on the scientific, technical and legislative requirements and coordinates the Australia's national measurement system.

2006

Stephen Hawking was presented with the Royal Society Copley Medal for his contributions to theoretical physics. Before Stephen Hawking received his Copley Medal from the Royal Society, it was first flown into space aboard NASA's Space Shuttle.

2007

The Council of Australian Governments (COAG) agreed that the Commonwealth should assume responsibility for trade measurement.

Australian scientists are to use two highly polished spheres to determine how many silicon atoms make up a kilogram. This could then be used as the new definition, bringing the kilogram into line with other base units such as the metre and the second, which are all defined by physical constants. This is a truly international project in that the silicon, which has taken three years to produce, was made in Russia and grown into a near-perfect crystal in Germany. See: **http://www.theage.com.au/news/national/making-an-exact difference/2007/06/14/1181414466901.html**

2008

The BIPM still has its headquarters near Paris, in the grounds of the Pavillon de Breteuil. Surrounding the Pavillon de Breteuil is the 'Parc de Saint-Cloud'. The French Government placed this land at the disposal of the BIPM; its area of 43 500 m^2 (4.35 hectares) is regarded as international territory, and its upkeep is financed jointly by the Member States of the *Treaty of the Metre*.

The BIPM has a staff of about 70 and its status is similar to that of other inter-

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government organizations based in France. The physicists and technicians who work at the BIPM conduct measuring research called metrological research. Their main jobs are to make international comparisons of the realisations of units, and to check the standards used in metrology.

Because of the range of work carried out by the BIPM, the CIPM has set up Comités Consultatifs to which it can refer matters. The Committees can form temporary or permanent working groups to study special subjects, and they are responsible for coordinating the international work carried out in their respective fields, and for proposing recommendations concerning units.

The Committees have common regulations and they meet at irregular intervals. The chairman of each Consultative Committee is designated by the CIPM. The members of the Committee are usually people from metrology laboratories and specialized institutes, together with representation from the BIPM. At present there are ten such committees:

Consultative Committee for Electricity and Magnetism (CCEM)
Consultative Committee for Photometry and Radiometry (CCPR)
Consultative Committee for Thermometry (CCT)
Consultative Committee for Length (CCL)
Consultative Committee for Time and Frequency (CCTF)
Consultative Committee for Ionizing Radiation (CCRI)
Consultative Committee for Units (CCU)
Consultative Committee for Mass and Related Quantities (CCM)
Consultative Committee for Amount of Substance (CCQM)
Consultative Committee for Acoustics, Ultrasound and Vibration (CCAUV)

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TIMELINE OF THE METRE

Year	Definition of the Metre
1790 May 8	The French National Assembly decreed that the length of the new metre would be equal to the length of a pendulum with a half-period of one second.
1791 March 30	The French National Assembly accepted the proposal from the French Academy of Sciences that the new definition for the metre be equal to one ten-millionth of the length of the Earth's meridian – the distance from the equator to the north pole – along a quadrant that passed from near Dunkerque in France and Barcelona in Spain.
1793 August 1	The definition of the metre as 1/10 000 000 of the distance from the North pole to the equator was confirmed.
1795 April 7	A provisional metre bar was constructed of brass
1799 December 10	The French National Assembly specified the length of a platinum metre bar, constructed on 23 June 1799 and deposited in the National Archives, as the final standard of length for the metre.
1889 September 28	The first *General Conference on Weights and Measures* (CGPM) defined the metre as the distance between two lines on a standard bar of an alloy of platinum with ten percent iridium, measured at the melting point of ice. This International prototype platinum-iridium metre bar had a cross-section shaped like an X to give it more stability.
1906	The length of the metre was re-specified as 1 000 000/0.643 846 96 wavelengths in air of the red line of the cadmium spectrum.
1927 October 6	The seventh CGPM adjusted the definition of the metre to be the distance, at 0 °C, between the axes of the two central lines marked on the prototype bar of platinum-iridium, this bar being subject to one standard atmosphere of pressure and supported on two cylinders of at least ten millimetres diameter, symmetrically placed in the same horizontal plane at a distance of 571 millimetres from each other.
1960 October 20	The eleventh CGPM defined the metre to be equal to 1,650,763.73 wavelengths in vacuum of the radiation corresponding to the transition between the 2p10 and 5d5 quantum levels of the krypton-86 atom.
1983 October 21	The seventeenth CGPM defined the metre as equal to the distance (l) travelled by light in vacuum during a time interval of 1⁄299 792 458 of a second.
2002	The CIPM recommended that the 1983 definition be restricted to: *lengths* (l) *which are sufficiently short for the effects predicted by general relativity to be negligible with respect to the uncertainties of realisation.*

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Conclusion

It's hard to pinpoint the exact date that the modern metric system, the International System of Units (SI), actually began. What is a young student to do when confronted with the question: *when was the metric system invented*?

- ⊇ Did the International System of Units (SI) begin when the Royal Society published John Wilkins', '*An Essay Towards a Real Character and a Philosophical Language*' on **1668 April 13**?
- ⊇ Do we take the date of the decision of the Académie Française to promote a decimal system on **1790 August 22** as the starting point?
- ⊇ Do we take the issuing of the first report of the French Academy of Sciences who in their first report of **1790 October 27** recommended the decimal division of money, weights, and measures for France?
- ⊇ Do we take the date of the original French legislation, on **1791 March 26**, or do we consider the date(s) of subsequent legislation?
- ⊇ Do we use the legal origin of the metre as the day when the Republican Government of France adopted a report from the Académie Française and decreed the unit of length was to be called the 'metre' and it was to be 1/10 000 000 (10^{-7}) of the earth's quadrant on **1793 August 1**.
- ⊇ Do we take the day that the Republic of France legally adopted the Academy of Sciences' recommendation for a decimal metric system on **1795 April** 7.
- ⊇ Some say that it's better to date the metric system from a definite event, such as the deposition of the two platinum standards, in the Archives de la République in Paris on **1799 June 22**. This event is regarded as of prime importance by the BIPM, who say that this is a key to the development of the international system of units.
  The BIPM brochure says:

The creation of the Decimal Metric System at the time of the French Revolution and the subsequent deposition of two platinum standards representing the metre and the kilogram, on 22 June 1799, in the Archives de la République in Paris can be seen as the first step in the development of the present International System of Units.

The future

Science and technology, by their nature, are constantly changing. We can expect many new demands for new measuring methods as sciences and technologies develop. However there will always be a need for standardisation, so the international and national standards institutions will remain, but they will often have to operate differently. For example, in the early 21st century, we are seeing a trend toward online calibration, where software at a standards institution can analyse the measurements from a remote machine, even control the measuring equipment at a distant laboratory, and can then issue a test certificate showing its accuracy and its precision. This is already possible using standard computer connections over the internet.

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References

BIPM

The definitive source of information about the International System of Units (SI) is from the BIPM. You can access the English language web pages at: **http://www.bipm.org/en/home/ or you can download a complete copy of the** International System of Units (SI) brochure from **http://www.bipm.org/en/si/si_brochure/general.html where section 1.8 is a relevant** 'Historical Note'.

For those particularly interested in history you might like to refer to: **http://www.bipm.org/en/si/history-si/ and http://www.bipm.org/en/bipm/history/**

ISO

ISO 31. Quantities and Units. International Organization for Standardization (ISO), Geneva, Switzerland. 1992-1998 (14 volumes). Available in the U.S. from the American National Standards Institute (ANSI). Comprehensive description of physical quantities, their symbols, and the SI units used to measure them. Volume 0 covers general principles and rules for correct use. This document is available for purchase.

NIST

Free copies of the *Guide for the Use of the International System of Units (SI)* can be downloaded at NIST SP 811. It is published by the National Institute of Standards and Technology (NIST), Gaithersburg, MD 20899-0001. Special Publication 811. The 1995 edition has 74 pages and it gives detailed rules for using SI, explains the rounding rules, and lists numerous compound derived units. Lists deprecated (obsolete) metric units and conversion factors to be used for converting some 400 non-SI units to SI.

NIST also has two web pages that give relevant information on the history of the metric system in the USA. You can find them at:

http://ts.nist.gov/WeightsAndMeasures/Metric/lc1136a.cfm and http://www.mel.nist.gov/div821/museum/timeline.htm

ANSI

Standard for Use of the International System of Units (SI): The Modern Metric System is a 70 page American National Standards Institute (ANSI) document published by the Institute of Electrical and Electronics Engineers (IEEE), and the American Society for Testing and Materials (ASTM International). This document is available for purchase from **ANSI**

ATI

The Applied Technology Institute (ATI) has a broad view of the metric system at **http://www.aticourses.com/international_system_units.htm**

'The International System of Units – Its History and Use in Science and Industry', is an article by Robert A. Nelson.

Egypt

The University College of London web pages at **http://www.digitalegypt.ucl.ac.uk/weights/lenght.html** provide reliable information on the history of Egypt.

Metric Methods

Jim Frysinger's Metric Methods web page contains reliable reference information that is particularly relevant to the USA. You can find the Metric Methods web page at

CGPM	General Conference on Weights and Measures
CIPM	International Committee for Weights and Measures
BIPM	International Bureau of Weights and Measures
CCE	Consultative Committee for Electricity; now the CCEM – Consultative Committee for Electricity and Magnetism
BAAS	British Association for the Advancement of Science
AAAS	American Association for the Advancement of Science

http://www.metricmethods.com

The UK Metric Association has an interesting insight into the development of the metric system in the UK where Jim Humble OBE writes of:
'Historical perspectives by the last Director of the UK Metrication Board'.

See **http://www.metric.org.uk/press/humble.htm**

USMA

The United States Metric Association (USMA) has a chronology of the SI metric system that lists the important dates in the history of the modern metric system at **http://lamar.colostate.edu/~hillger/dates.htm** You can contact USMA through this link.

USMA also publishes the USMA SI Guide. It is a Guide to the Use of the Metric System (SI Version), 17th edition, 2007 with 34 pages. It is a primary source of information for using the modern version of the metric system (SI) and it is available for $18 post paid from: USMA, 10245 Andasol Avenue, Northridge CA 91325-1504. Phone/Fax: 818-363-5606

John Wilkins

See my articles

Tito Livio Burattini

http://www.roma1.infn.it/~dagos/history/sm/node19.html

Simon Stevin

http://en.wikipedia.org/wiki/Simon_Stevin

The Measure of Enlightenment

http://publishing.cdlib.org/ucpressebooks/view?docId=ft6d5nb455&chunk.id=d0e9255&toc.depth=1&brand=ucpress

Books

‘Measures and Men’ by Witold Kula (Translated by R Szreter), Princeton University Press 1986

‘The Curious Life of Robert Hooke: The Man Who Measured London’ by Lisa Jardine HarperCollinsPublishers 2003
