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COMMENTARY

Measure for measure

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The present system of measures for length, weight and capacity (volume) originates from scientific ideas expressed during the French Revolution in 1789. The history of a compatible unit of length, however, turns out to be less of a scientific but rather of a political character. Here reports to the *Philosophical Magazine* made in the first quarter of the nineteenth century are used to trace the cultural split between meters and inches, and between kilograms and pounds, that can be experienced in many parts of the world.

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1. Introduction

Up to the French Revolution in 1789 each European country had its own units for length, weight, volume and – by the end of the eighteenth century – also for temperature. Partially induced by the increasing world trade, in particular with Far Eastern countries, but also as a consequence of the Enlightenment, the idea of creating locally independent measures for distances and weight arose. It is quite amusing how well the Archives of the *Philosophical Magazine* reproduce the ''national character'' of measuring units. The title of the play (comedy), believed to be written by William Shakespeare between 1603 and 1604, seems to fit – at least taken literally – as an answer to the question why in English speaking countries daily life measures do not reflect the metric system.

Nowadays in all scientific matters the *International System of Units* (SI) is used, in which the properties of any ''quantity'' Q can be expressed as a product of fundamental units,[1]

$$[Q] = \left[10^n \,\mathrm{m}^\alpha \cdot \mathrm{kg}^\beta \cdot \mathrm{s}^\gamma\right] \cdot \left[\mathrm{A}^\delta \cdot \mathrm{K}^\varepsilon \cdot \mathrm{mol}^\zeta \cdot \mathrm{cd}^\eta\right], \tag{1}$$

where m refers to meter, kg to kilogram, s to seconds, A to ampere, K to kelvin, and cd to candela. We are so used to this system that the original difficulties in defining these fundamental units are almost forgotten. Forgotten also seems to be the reason why the International System of Units, which in turn is related to an earlier system of units, namely the *cgs* (centimeter-gram-second) system, is universally used only in

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science, while various historical "left-overs" haven't lost their popularity in mainly English speaking countries.

2. Measure …

"*As the measurements of the earth, and researches respecting the figure of it, had, at various times, and in different countries, during the course of the* 18*th century, been an object of the labours of the most distinguished philosophers, when an idea was lately conceived in France of deducing from the dimensions of our globe a standard of unity, to which every thing susceptible of measurement or weight could be referred, it was necessary to make an effort proportional to the importance of an enterprise become a national concern. In the midst, therefore, of a long and destructive war, and admidst a thousand difficulties of every kind, a series of triangles between Dunkirk and Barcelona, comprehending the tenth of an arc of the meridian extending from the equator to the pole, that is to say, the fourth part of the whole circumference of the globe; and the ten-millionth part of this arc so determined was adopted as representing the unity of the whole metric system. This plan was executed with standards composed of substances capable of resisting the influence of weather; and then by establishing, as was carefully done, the exact ratio of the length of a metre to that of a common pendulum which swings seconds, on the border of the sea, in a given latitude, the determination of this unity was rendered independent of any catastrophe that might alter or destroy its types, in the construction of which all those resources presented by philosophy and the arts, now brought to a very high degree of perfection, were employed*" (M.A. Pictet, *Comparison of the definitive metre with a standard of English measures, carried from London to Paris* [1]).

The mètre (meter, metre), i.e., the ten-millionth of the distance between the North Pole and the equator at the longitude of Paris, became the legally approved unit of length in France by August 1, 1893. However, because of the difficulty in reproducing the corresponding measurement (finished only in 1798), a platinum bar nominally of that length was constructed in 1799. This platinum bar was eventually replaced in 1889 by an X-shaped one consisting of 90% Pt and 10% Ir, leading in turn to a slight redefinition of the meter, which then served as standard of length till 1960.

The reason for a comparison to the length of a second swinging pendulum mentioned in the above quote [1] was that such a pendulum was also suggested (around 1790) to serve as a standard unit of length. It was found eventually, however, that its dependence on gravity was too big for the required purpose. Thus in the end only the definition of a meter based on a quarter arc of the globe survived. To be sure that the phrase "in the end" is properly understood, it will be shown that many years after Pictet's report [1] a second swinging pendulum still served as the official standard of the British unit of length.

3. … for measure

Since, starting in about 1775, a decades-long project to produce a new map of Great Britain was launched, it became necessary to compare the English standard

of length with the newly defined meter. For this reason "*a standard of the English measures on a brass ruler*, *strong and well polished*, *about* 49 *English inches in length*, 36 *of which make the English yard*, *and divided along its whole length*, *by lines exceedingly into tenth of an inch*" [1] was carried to Paris in 1801 and compared with the platinum meter. "*It was found that at a temperature of* 15.3 *degrees of the centigrade thermometer the platina metre was equal to* 39.3775 *English inch*".

Clearly such a comparison, in particular considering the inherent difference in the temperature dependence of the elongation of the two metal objects, provoked not only a discussion about the precision of the measurements, but also an opinionated battle about the usefulness of adopting "foreign measures". At any rate, the scientifically interested public in England seems to have already been confused enough just about a proper conversion of the new (French) length standard to the old French standard. At least this problem was eventually resolved in a report entitled *On the French measures and weights* [2]: "*the value of the métre in the old measures* (is stated) *to be* 36 *pounces* 11 *ligues and* 296 *thousands of a ligue*. . . .*This measure reduced will equal pieds* 3.0784". As can be imagined the insufficient number of decimal places gave additional worries once square or cubic meters had to be considered.

The Select Committee on Weights and Measures of the House of Commons, originally appointed in 1758, made no attempt to adopt the new French ideas. On the contrary, it insisted on using a second swinging pendulum – of course located in London – as the standard of length,

Definitions of standards of length, *weight and capacity Report* [3] *from the Select Committee on Weights and Measures*. *Ordered by the House of Commons*, *July* 1, 1814.

	One yard of 36 *inches*	*is such*, *that a pendulum of* 39.13 *inches vibrates seconds in London*
1 *Avoirdupois*	*One pound of* 16 *ounces*	*is such that* 1 *cubic foot of water at* 56.5° *F weighs* 1000 *ounces*
1 *Troy*	*One pound of* 5760 *grains*	*is such*, *that* 7000 *grains* = 1 *pound* (*Avoirdupois*)
	One gallon of 8 *pints*	*maybe such that it contains* 10 *pounds of distilled water at the temperature of* 56.5°, *with convenience*.

but also confirmed most of the units in use then:

"Traditional" units as defined in the same report [3]

	cubic inch	
The gallon of 10 lb.	282	Beer gallon
	231	Wine gallon
The pint of $1\frac{1}{4}$ lb.	104.4	Stirling jug
Bushel of 80 lb.	2150.42	Winchester bushel
A cylinder of $18\frac{3}{4}$ diam.	2208.9	Approximate bushel
	2211.84	New bushel

In a *Proposal for a new regulation of weights and measures* [4] it was even suggested that the unit of length, namely the length of the second swinging pendulum in London, should be called a *Pendulum* and parts or multiples thereof in analogy to the French units a *Millipendulum* or a *Kilopendulum* with counterparts such as *Kilogallons* or *Kilopounds*. The reasons for the proposal were based on the idea that it was by no means proven that an arc-related definition of length was superior to that of a pendulum.

At this stage one ought to remember certain aspects of European history. It was by no means a coincidence that the report of the parliamentary committee appeared in 1814, since this was the year of the final defeat of Napoleon and the end of French supremacy over Europe. The public political opinion simply reflected this military success, and, in addition, the feeling of having remained the only surviving "superpower". In 1815 the Viennese Congress started re-establishing the old order, the old system of monarchies. The prevailing feeling of superiority can easily be seen in a report entitled *On the length of the French métre estimated in parts of the English standard* [5], in which another, supposedly more precise, comparison to the platinum meter is discussed. The connotation of *English standard* with a pluralistic "we" is more than obvious and was clearly intended.

In 1819 the commissioners (now) appointed by his *Royal Highness* proposed [6] again with respect to the English standard "*upon the authority of the experiments made by the Committee of the Royal Society, that it should be declared, for the purpose of identifying or recovering of this standard, in case that it should be ever lost or impaired, that the length of a pendulum vibrating seconds of mean solar time in London, on the level of sea, and in vacuum, is* 39.1372 *inches of this scale; and that the length of the metre employed in France, as the ten-millionth part of the quadrantal arc of the meridian, has been found equal to* 39.3694 *inches*".

With respect to weight the same commission declared [6] "*that a cubic foot of distilled water, at the temperature of* 56.5° *on Fahrenheit's thermometer, and under an atmosphere pressure measured by* 29.76 *inch on the barometer, weighs precisely* 1000 *ounces avoirdupois*".

In the *Third report of the commissioners appointed by his Majesty to consider the subject of weights and measures* [7,8] the final decision of this commission is summarized:

"*We beg therefore finally to recommend, with all humility to Your Majesty, the adoption of the regulations and modifications suggested in our former reports, which are principally these*:

(1) *That the Parliamentary standard yard, made by Bird in* 1760, *be henceforward considered as the authentic legal standard of the British empire; and that it be identified by declaring that* 39.1293 *inches of this standard, at the temperature of* 62° *of Fahrenheit, have been found equal to the length of a pendulum supposed to vibrate seconds in London, on the sea level, and on vacuum.*

(2) *That the Parliamentary standard Troy pound, according to the two-pound weight made in* 1758, *remained unaltered; and that* 7000 *Troy grains be declared to constitute an Avoirdupois pound; the cubic inch of distilled water being found to weigh at* 62° *in a vacuum,* 252.72 *parliamentary grains.*

(3) *That the ale and corn gallon be restored to their original quality*, *by taking*, *for the statutable common gallon of the British Empire*, *a mean value*, *such that a gallon of common water may weigh* 10 *pounds avoirdupois in ordinary circumstances*, *its content being nearly* 277.3 *cubic inches*; *and that the correct standards of this imperial gallon*, *and of the bushel*, *peck*, *quart*, *and pint*, *derived from it*, *and their parts*, *be procured without delay for the Exchequer*, *and for such offices in Your Majesty's dominions as may be judged most convenient to the ready use of Your Majesty's subjects*".

This was the final restoration of the traditional British units of length, weight and capacity. The only topic left to discuss was the subdivisions of an inch, namely in $\frac{1}{2}$, $\frac{1}{4}$ and $\frac{1}{8}$ of an inch. In 1824 a Mr. Thomas Tredgold [9] expressed his opinion about the traditional subdivisions as follows: "*I am glad that so much of our old measures and weights are to be preserved. . . . What foundations has this decimal system in the nature of things*? – *will it continue for ever to be the best possible system of notation*? *or*, *is it itself imperfect and likely to be changed as soon as a better shall appear*? . . . *The decimal system owes all its advantages to the happy thought of arranging numbers according to their powers*; *but this arrangement is not peculiar to it*. . . . *Apparent simplicity*, *is not a test of the merit of any invention*, *unless that simplicity be accompanied by fitness for the objects it is to accomplish*; *and it is not much in favour of the decimal scale to remark*, *that there* 4 *out of* 9 *digits of which the reciprocals cannot be expressed in finite terms*; *viz*. $\frac{1}{3}$, $\frac{1}{6}$, $\frac{1}{7}$, *and* $\frac{1}{9}$ . . . . . *The advocates for formal division do not appear*, *as far as I have seen*, *to have studied the nature and advantages of the old divisions*. *For example*, *in the division of time all the prime digits are factors . . . the only prime digit not included being* 7 . . . ."

This opinion was only opposed in terms of money units: "*Decimal coins and money accounts*, *if adopted by the government*, *as already is the case in enumerating their millions*, *and with all sums above* 20 *shillings*, *and even these are decimally stated when above* 9 . . ." [10], but not as far as the measuring units were concerned.

4. Final remarks

Perhaps it should be recalled that only since 1960 have the SI units become internationally adopted. The units of length, weight and temperature are now defined by

SI units

m	The meter is the length of the path travelled by light in vacuum during a time interval of 1/299 792 458 of a second
kg	The kilogram is the unit of mass; it is equal to the mass of the international prototype of the kilogram
s	The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium 133 atom.
K	The kelvin, unit of thermodynamic temperature, is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water.

and are, with the exception of the kilogram, based on natural constants.

If, however, despite International Units one wonders why a tape measure in the US or in Britain shows lengths in inches and usually the smallest subunit is an eighth of an inch, or, going shopping in France or in Germany everything has to be ordered by gram or kilogram, while in English speaking countries ounces or pounds are used, then the reason for this incompatibility of daily life cultures has to be traced back to the beginning of the nineteenth century, and is related to the fact that after 1815, after the defeat of Napoleon, in the course of the restoration of the *ancien regimes*, all innovations of the French Revolution were abandoned outside continental Europe. If one wonders why 1 *Imp.fl.oz*. corresponds to 28.4130642624675 ml (cm^3), while 1 *US fl.oz* equals 29.5735295625 ml (cm^3), or, specifically, in Britain beer is measured in pints rather than in fractions of a liter (1000 cubic centimeters), then one has to admit that this is only because of historic political reasons that usually are hardly remembered. The decimal system – as perhaps is well known – also took a long time to enter the British currency system: only since 1971 has the pound consisted of 100 pence.

The Archives of the *Philosophical Magazine* give a very precise account of the history of measures in the English speaking world during the last 200 years. It is a pleasure to discover there scientific and less scientific, i.e., political arguments concerning the system of measures.

Note

1. The second square bracket refers to units discussed at least half a century later than the ones in the first square bracket.

References

[1] M.A. Pictet, Phil. Mag. Series 1 12 (47) (1802) p.229.
[2] Phil. Mag. Series 1, 43:189 (1814) p.7.
[3] Phil. Mag. Series 1, 44:197 (1814) p.171.
[4] Phil. Mag. Series 1, 46:208 (1815) p.113.
[5] H. Kater, Phil. Mag. Series 1 52 (248) (1818) p.431.
[6] Phil. Mag. Series 1, 54:257 (1819) p.172.
[7] Phil. Mag. Series 1, 57:277 (1821) p.359.
[8] Phil. Mag. Series 1, 57:278 (1821) p.430.
[9] Phil. Mag. Series 1, 64:318 (1824) p.302.
[10] Phil. Mag. Series 1, 64:319 (1824) p.362.