DOUBTS ABOUT UNITS OF MEASURE

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METRE, KILOGRAM, SECOND, mole, ampere, kelvin, candela

A few years ago I pondered about a problem of metrology, which I now take up again because it seems to be an important one; firstly however, I will attempt an explanation of it even though, apparently, extremely few people to date have thought about it.
Although this is a summary at best, we must go back in time – to be precise, 1874 – when the British Association for the Advancement of Science formally introduced the CGS System of Weights and Measurement, based on three units – centimetre, gram, and second – and which was welcomed by physicists whose experiments often involved very small quantities. And so it was: in the age of yards and ounces, there came the official introduction of a measurement system based on units originating from the despised French Revolution!
The term "Advancement" certainly applied here!
Not long after, in 1889, the famous International Bureau of Weights and Measures introduced a variant, the MKS System, also based on three units – metre, kilogram and second – which was more practically convenient especially for engineers who, at that time, were designing huge ships and other constructions made of steel, a new material also used for the Eiffel Tower.
So far so good. The birth of radio telecommunication and its rapid evolution during the first half of the 1900s was perfectly supported by the CGS System until, in 1954, the 10th General Conference on Weights and Measures deemed it necessary to unify the two Systems and adopted a new System of Measurement, this time based on seven units: **m**etre, **k**ilogram, and **s**econd (as before), but also (apart from the innocuous mole) ampere, degrees kelvin, and candela.
Ultimately the 11th General Conference on Weights and Measures, in 1960, decided that the new System would officially be called the International System of Units, or **SI** (*Système International d'Unités*), and its adoption was imposed world-wide.
It was unanimously accepted, very quickly by the technical-scientific world, not so quickly by the legislation of some countries, and rather slowly by citizens of Anglo-Saxon countries (the USA still uses yards and ounces), but there was no protest because the metre, kilogram, and second were by now commonplace, as was light based on incandescent lamps, and therefore a specific unit of measurement (the candela, based on incandescence) was very useful, while a unit of absolute temperature signified an operational simplification.
The ampere, the unit denoting the electric current going into every house to power refridgerators, washing machines, and even the relatively new (at the time) televisions, certainly didn't upset anyone, despite some protest from the telecoms industry, who were concerned about their calculations becoming more complicated (but were immediately accused of living in the past - *laudatores temporis acti*).
In 1964 when I was studying engineering at university, the CGS System was no longer in use, even in Physics; its existence was taken as historical fact, but was effectively considered obsolete. Since then, who would ever have considered comparing the two Systems, and why would anyone have wanted to?
Let's do so now. In the **SI** system electric charge **Q** is defined below:

$$Q = i\,t$$

Dimensionally it equals *[t i]*
where *i* = current and *t* = time.

In practice the SI system defines the unit of current (1 ampere) as being the current required to produce a force of 2 x 10^{-7} Newton (where Newton is unit of force) per 1 metre of length on two parallel wires (of negligible thickness) placed 1 metre apart (metre is the unit of length) in a vacuum.
Now that current and time have been defined, let’s now look at charge (coulomb), that being the amount that flows through a conductor every second with a current equal to 1 ampere. In the **SI** system, the equation that should be used to define current is used to define charge: not **i = Q/t**, but **Q = i t.**
In this way, the definition of charge as a fundamental unit disappears from the **SI**, even though it’s even present in elementary particles – about as fundamental as it gets!
Even so, incredibly, it all works perfectly!
It’s a pity that this definition is useless; a better one would be based on the unitary value of a force to which a point charge is subjected, placed at a unitary distance from another equal charge. In fact, it would be logical to actually start from the electric charge, which is an entity in and of itself independent of time, instead of honouring it with a characteristic that is clearly derived from it, such as current, which has to be defined through both electric charge and time.

In the electrostatic **CGS** System (there was also a less used electromagnetic one) electric charge is defined through Coulomb’s Law, for good reason, which says, regardless of charge sign:

*The force **F** between two point charges in a vacuum is equal to the product of the values of the two charges (${q_1}$ e ${q_2}$), divided by the distance **r** squared.*

$$F = (q_1\, q_2) / r^2$$

If both charges have the value of 1, the equation becomes:

$$F = q^2/r^2$$

From which we derive:

$$q = r\,\sqrt{F}$$

Dimensionally therefore, the electric charge is $[\, l^{2}\, m\, t^{-2}]$
with *l* = length, *m* = mass and *t* = time

The conversion of the CGS electric charge, which is static, to the SI, which is in motion, is anything but banal and is discouraging to those wanting to take it on, especially as there is no real reason for it; nevertheless a conversion is possible and legitimate.
If we take the dimensional definition of the CGS System’s electric charge and introduce it into the SI, the first consequence is a change in the dimensional definition of the electric current, together with that of all the expressions in which current appears.
From the latter, various correlations between length, time, mass, magnetic flux (magnetic equivalent of electric charge) and magnetic field intensity emerge.

A further consequence is the desire to also substitute mass with its energetic equivalent. Remembering Einstein:
Energy is equal to mass multiplied by the speed of light squared ($E = mc^2$).
Carrying out this substitution opens a new world full of unexpected correlations that link electric charge, electric field intensity, magnetic flux, magnetic field intensity, time, energy, force, power, length, volume, and mass.

A similar but less serious problem is also posed by the candela, a fundamental SI unit in reality itself derived, which in actual fact depends on the number of light photons (visible to us) emitted per second by a given source; it would be more logical to use the energy emitted per second (i.e. power), also specifying the wavelength range, giving rise to an absolute valid definition without the need to coin a new fundamental characteristic.
It really does seem as if commercial needs were placed above logic. Even absolute temperature (degrees Kelvin), as convenient as it is for calculations, does not represent a fundamental characteristic, because it's nothing other than a function of the energy of a single particle and therefore depends on its speed (length/time) and mass.

The mole, on the other hand, doesn't pose serious problems, because it can be reduced to a pure number – Avogadro's number – which only poses the not insignificant problem of correctly counting the number of atoms in 12 grams of carbon for the ^{12}C isotope. Once established with enough precision, the number of elementary particles of a substance in one mole of this same substance can be determined unequivocally.

Since it is possible to define every other characteristic using only **length, mass**, and **time**, as in the CGS System, it seems logical to assume that **only these three are effectively fundamental**. At worst we can debate whether to use mass or energy, because as we have seen, they are closely correlated.
So why this three-card game? Or more like, three new fundamental characteristics?
Poiché si tratta di un Sistema di Misura Internazionale che ne sostituisce, abrogandolo, un altro che aveva funzionato bene per molti decenni, non posso credere all'incompetenza e alla distrazione di tutti i membri della commissione: è ovvio che la scelta è stata fatta deliberatamente.
Since we have an International System of Measurement that substituted and revoked another that worked well for many decades, I can't believe that incompetence and oversight of the commission's members was the cause; obviously it was chosen deliberately.
The ancient Romans, well versed in the art of deception, used to say "Cui prodest?", whereas now we say "Who benefits?", but the concept is the same and the deception, if it exists, is also the same. Naturally now, like then, it is passed off as a benefit.

WAS THE TRUE INTENTION A SUPERFICIAL SIMPLIFICATION FOR COMMERCIAL REASONS OR WAS IT POSSIBLY TO PREVENT NEW INCONVENIENT DISCOVERIES?
The desire to also substitute mass with its energetic equivalent, as mentioned above, is irresistible, and in fact has been done in the new SI System of Measurement and here are the consequences.

THE THREE FUNDAMENTAL UNITS OF MEASUREMENT (m, Kg, s)

THE METRE (m)

Positing:

- f = frequency, expressed in Hertz (periods per second)
- T = period, linked to frequency by the definition: $T = 1/f$
- c = speed of light in a vacuum, expressed in m/s
- λ = wavelength in a vacuum, expressed in metres

From the definition of velocity = distance/time, assuming velocity is that of light in a vacuum (c), distance being wavelength (λ) and time as being the oscillation period (T) of a given (sample) frequency generator, we get the following:

$$\mathbf{c = \lambda/T}$$

from which we derive:

$$\mathbf{\lambda = c\,T = c/f}$$

In practice the wavelength λ of the frequency generator depends on the speed of light c, assumed to be a constant, and on the frequency f of the generator itself, which is also a constant, and therefore **the unit of length (metre) is defined as a certain number of standard wavelengths.**

THE SECOND (s)

If an atom is excited, one of its outer electrons acquires a particular amount of energy and reaches a higher energy state, then upon its spontaneous return to its resting level it emits exactly that same amount of energy in the form of photons.
Positing:

- E = energy, expressed in Joules
- h = Planck's constant, expressed in Joules per second (energy per unit of time)
- f = frequency, in Hertz (periods per second)
- T = period, linked to frequency from: $T= 1/f$

The relationship between energy and frequency of those photons is:

$$\mathbf{E = h\,f}$$

from which:

$$\mathbf{f = E/h}$$

or also:

$$\mathbf{T = h/E}$$

If we choose particular atoms in gaseous form and excite them in a controlled manner, then make them pass through a hole into a cavity, they continually emit photons with a constant energy E. Given that h is also a constant, the frequency f associated with those photons, as detected by a sensor in the cavity, is constant.

Since $T = 1/f$, the period T corresponding to this constant frequency f is also constant. Consequently, using an appropriate counter, **it is possible to count single cycles of period T and choose a number of them to define the given unit of time (the second).**

THE KILOGRAM (kg)

So far the kilogram is the only unit of measurement not defined by a physical property but by a manufactured one: a platinum-iridium cylinder that replicates, in the easiest usable form, the mass of one cubic decimetre of triple distilled water at 3.98 °C (temperature at which water is at its maximum density) at standard atmospheric pressure.

There are currently several attempts underway, based on various physical principles, aimed at also linking the unit of mass to physical constants. The closest to being successful is based on Planck's constant and its success is predicted to occur in the near future.

Positing:

f = frequency, in Hertz (periods per second)
T = period, linked to frequency from: $T = 1/f$
c = speed of light in a vacuum, expressed in m/s
h = Planck's constant, expressed in Joules per second (energy per unit of time)

and knowing that energy is:

$$E = h f$$

or also, from the well-known equivalence of mass and energy:

$$E = m c^2$$

Combining the two energy equations we get:

$$h f = m c^2$$

from which:

$$m = h f/c^2$$

Assuming c, e, and h are constants, we only need a constant frequency generator and we can define a standard quantity of mass as a function of a chosen frequency (standard mass submultiple), or also define an exact mass correlated to the available standard frequency. In fact, taking $K = h/c^2$ = constant, we obtain:

$$m = K f$$

A determined number of standard quanta would therefore define the unit of mass (the kilogram).

DOUBTS

Apart from a couple of non-disputable simple definitions, such as: period = 1/frequency, velocity = distance/time, and wavelength = speed of light in vacuum/frequency, two physical principles are used: $E = h\ f$ and $E = m\ c^2$, which are eventually condensed into the following formula:

$$\mathbf{m = h\ f/c^2 = h/(T\ c^2)}$$

This equation clearly contains two universal constants, **h** and **c**, as well as **T**, which is the period of the sample frequency generator.
Since, therefore, $\boldsymbol{\lambda = c\ T\ ;\ T = h/E}$ and $\mathbf{m = h/(T\ c^2)}$, if the sample mass is defined as a function of Planck's constant (h), both standard mass itself and standard time will depend on the velocity of light (mass being directly related to the square of that velocity) and all three standard measurement units will depend on the constancy of the standard frequency (and therefore its period T), always assuming that the energy associated with a particular energy level jump of a specific electron from a specified type of atom is constant everywhere.

From what is expounded above we see that as much as possible, with respect to the definition of the three fundamental units of measure, was done to resort to universal physical constants.
In practice everything works well if h, c, and T are effectively CONSTANTS EVERYWHERE in the entire universe.

But are universal physical constants truly CONSTANT and UNIVERSAL?
How can we prove that they really are constant, if to measure them we use standard units that are totally dependent on them?
How can we actually be sure that ALL physical "constants" that we define as "universal" remain the same even billions of light-years away, and in a universe that – according to the latest theory – has been continuously expanding for billions of years? Will the metre risk distension like the universe, producing measurements of distance that only appear constant, or will it shorten because the speed of light slows slightly with distance, thus producing measurements showing the universe to be expanding, when in fact it is stationary?

CAN WE RELY ON THEM, OR DO WE RISK BLIND FAITH IN MEASUREMENTS THAT IN REALITY ARE NOT REAL, OR AT LEAST INEXACT?

IF YES, THEN WHY?