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Proposal of an invariant mass reference for the kilogram

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Summary

The SI measurement system requires a universally invariant mass reference standard. History shows however, that the masses made of the material chosen in 1795 to manufacture the reference kilogram and its official replicas have drifted over time for various reasons, some known and some unknown.

This paper describes a possible explanation for one of these unknowns and a simple experiment that could confirm it. As an alternate method to the use of masses made up of atoms to define the standard, this paper proposes the use of a reference mass known to be universally constant, that is, the invariant rest mass of the electron, and summarily describes an apparatus making use of this invariant rest mass to uniformly calibrate balances anywhere on the Earth.

1.1 Brief History

It is a well documented fact that the standard kilogram stored in Sèvre, France, meant to be the universal standard mass unit of the SI measurement system, has been and still is the cause of major head scratching in the scientific community.

Originally meant to be part of a system unifying measurements, it was defined in 1795 as the mass of one cubic decimeter (1/1000 of a cubic meter, also defined as one litre) of distilled water at maximum density (precisely 276,984^{o} Kelvin) at one standard atmosphere. However, the connection between the standard kilogram and the cubic decimetre was cancelled in 1960 after renewed measurement revealed that the reference one cubic decimetre of distilled water at maximum density now had a density of 25 millionth of kg less than the Sèvre reference kilogram, with maximum error margin of only one millionth!

The measurement techniques available two centuries ago apparently already allowed precision in the 1 part per million range and the utmost care was lavished on all procedures spreading over many decades to insure accuracy.

The reference kilogram then produced in 1879 is a cylinder made of 90% platinum and 10% iridium, 39.17 millimeters high and 39,17 millimeters diameter stored in optimal conditions in Sèvre [**3**]. This alloy was chosen on account of its exceptional hardness and resistance to oxidation.

Official replicas of the official Sèvre kilogram were then manufactured to within a few micrograms of the original and sent to all participating countries and stored in similar conditions. Approximately every 50 years, each replica is carefully measured and compared to the Sèvre kilogram.

These periodic verifications have however been the cause of concern in the scientific community because despite all of the care taken, all replicas appear to have gained mass over the course of the past two centuries relative to the initial official Sèvre kilogram sample for a variety of reasons, some known related to ambient contamination and cleaning procedures, <u>and some that are still unknown</u>. The reality is that the masses of the complete set of all official replicas have been progressively diverging over time and that the original Sèvre kilogram seems to have lost about 50 micrograms with respect to the set of replicas.

It is not known what interpretation should be given to the phenomenon. Some possibilities are: 1) the Sèvre kilogram would be stable while the replicas gain mass over time. 2) the Sèvre kilogram would be losing mass while the replicas gain mass. 3) all kilogram samples would be gaining mass with the initial kg gaining mass less rapidly, etc…

The correct interpretation will become possible only when comparative volume measurement are accomplished over extended periods of time on the various official kilograms with the recently and permanently stabilized "meter" unit now referring to the invariant speed of light since it is not known (or studied yet) whether the volumes of the various reference masses have been varying also over time and that the analysis that follows seems to indicate that atomic volumes may depend on the local ambient gravity field intensity.

A variety of methods have been proposed to resolve the issue by defining a new standard for the kilogram that would be stable over time, like the new "meter" standard has now become. Some involve counting the atoms in a new reference mass, others involve accelerating known masses, etc. One of the methods most seriously considered involves defining the kg in terms of the Planck constant (h) termed the Avogadro project [**4**].

Another, conducted in the US involves measuring the electric power required to hold a mass of 1 kg against the force of gravity, termed the Watt balance project [**5**]. All of the proposed methods ultimately involve however <u>masses made up of atoms</u> being opposed one way or other to the <u>local intensity of the gravity field</u>.

The brief analysis that will now be conducted may however shed an entirely new light on the whole issue.

1.2 Argument

Since complete understanding of the nature of the forces involved inside nucleons has not yet been achieved, there remains a possibility that a relativistic mass component be an important fraction of the measured rest masses of atomic nuclei. Such a relativistic component may be all the more important since the experimentally confirmed possible range of masses of the only scatterable massive sub-component of nucleons (up and down quarks) represents such a small fraction of the measurable rest masses of nucleons.

Particle	**Estimated mass**	**Mass converted to kg**	**Reference**
Electron	0.510998910(13) MeV/c^2	9.10938215(45) E-31 kg	[2]
Up quark	1.5 to 5 MeV/c^2 (estimated)	2.049610923E-30 kg (approximate)	([1], p. 11-6)
Down quark	3 to 9 MeV/c^2 (estimated)	8.198443779E-30 kg (approximate)	([1], p. 11-6)
Proton	938.272013(23) MeV	1.672621637(83) E-27 kg	[2]
Neutron	939.565346(23) MeV	1.674927211(84) E-27 kg	[2]

Simple calculation from the maximum estimated MeV figures for the quarks shows that the only massive sub-components in a proton (uud) represent only about 19/938 = 2% of its measured rest mass. Similarly, the only massive sub-components in a neutron (udd) represent only about 23/939 = 2.4% of a neutron measured rest mass. A large part if not all the remaining mass of both types of nucleons seem to then be relativistic in nature.

Indeed, relativistic effects being tied to the velocity of massive particles and up and down quarks being massive and consequently being subject to gravity, there exists a strong probability that such relativistic effects defining the total mass of nucleons be due to highly relativistic velocities of these quarks within the confines of nucleons.

If this were the case, there consequently exists a strong probability that these velocities could be in part dependant on the local gravity field ambient intensity which is well documented to vary with location and altitude with respect to the Earth surface and that the rest masses of nucleons be variable to some extent.

Each quark of each nucleons belonging to a small amount of matter would be pulled outwards more strongly if this small amount is brought closer to a larger amount (a baseball being brought close to the surface of the Earth for example) as each quark making up the nucleons of this small amount would be attracted more strongly outwards by the increased number of quarks present in closer proximity on all sides making up the mass of the larger amount being brought closer, thus lowering its velocity and consequently its relativistic mass.

Conversely, it would be pulled outwards less strongly, thus increasing its velocity and relativistic mass[1], if the small amount to which it belongs was taken away from a larger amount (a baseball being taken away from the surface, by being put into orbit about the Earth for example).

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[1] This hints of course at the possibility that maximum nucleon density could be achieved only by small quantities of matter, ultimately by isolated nucleons, located in space far from any

However small these variations may be at the sub-atomic level for each nucleon in the possible range of the gravity gradient covering the various locations and altitudes of the surface of the Earth, they may possibly amount to a measurable difference for masses as large the 1 kilogram reference standard.

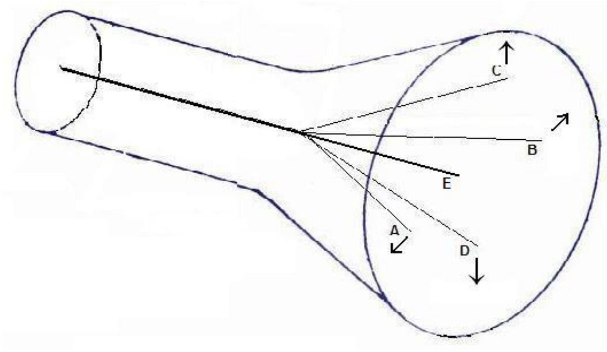
Three other factors need to also be taken into account. First, the position of the mass of the Moon with respect to the location where calibration measurements are taken, which represents a possible distance swing of up to 13000 km, and in maximum subtraction to the mass of the Earth if it reaches the zenith relative to the measurement location and in maximum addition if reaches the relative nadir; second, the cyclic variation in the local gravity field intensity from the Sun as the Earth-Sun distance varies on a yearly basis (a cyclic swing of about 5 million km), and third, the distance in the process of changing between the Solar system and the center of the galaxy due to the much longer cycle of the motion of the Solar system on its elliptical orbit about the center of the galaxy.

The first two cases can of course be minimized if measurements were to be taken at the same time of year and of the Moon cycle. These variations bring into perspective the possibility that any attempt to define an invariant mass standard involving complete atoms may be doomed by nature to be valid only locally and temporarily!

So what mass other than various types of atoms could then be used as an ultimate mass reference that would guarantee permanent stability over time?

1.3 A Universal and Invariant Mass Standard

An analysis of the complete set of stable massive particles other than atomic nuclei reveals that the only stable elementary massive particle for which there is absolute certainty that the rest mass is totally invariant across the universe, irrespective of gravity field intensity variations, is the electron (or positron) since, being elementary, its rest mass can harbour no relativistic component whatsoever, on top of having the smallest measured uncertainty margin of all massive particles (0.00000045 E-31 kg) compared to both types of nucleons (0.000000084 E-27 kg), that is 5 orders of magnitude smaller!



Technically speaking, we have been accelerating electrons for more than a hundred years and can even accelerate and detect individual electrons in more than one manner. Consequently, it would be technically possible to develop a special type of cathode ray tube to very precisely measure the invariant rest mass of the electron that could easily be produced in identically calibrated quantities to be used all over the world for required reference needs.

Defining very precisely tuned energy levels and guiding magnetic fields is largely within our technical abilities and only imply deflecting electrons in 4 separate directions: A and B being deflected horizontally respectively left and right at the same level in the gravity gradient; C being

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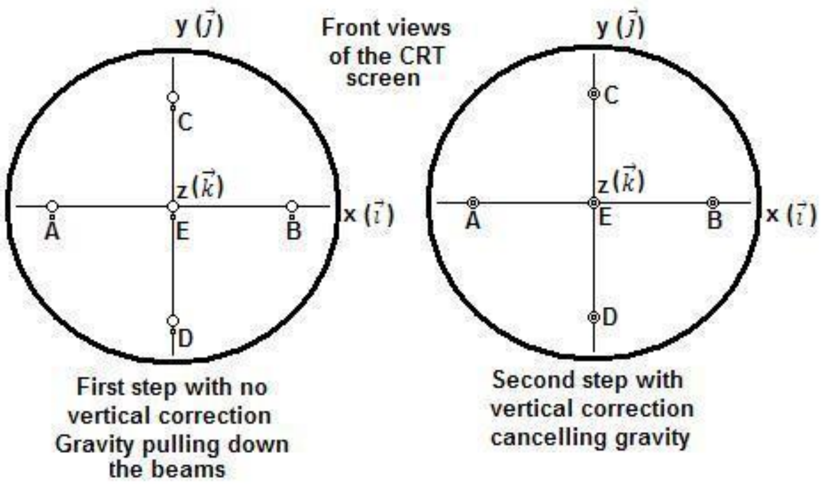
large planetary or stellar masses. But complete analysis of the implications of this possibility lies beyond the scope of this proposal.

deflected vertically up into the gravity gradient and D down deeper into the gradient and E being a reference projection suffering no deflection.

A neutral reference target E would be located at the geometric center of the screen and the four peripheral targets would be at equal distances from target E. The screen must be curved so that all 5 beams run exactly the same distance to their respective target from the point of emission.



Front views of the CRT screen

First step with no vertical correction Gravity pulling down the beams

Second step with vertical correction cancelling gravity

The first front view figure shows where the impact points of the 5 electron beams would be if the correct energy was applied and their trajectories deflected towards the exact centers of the 5 targets, with no correction being applied to take gravity into account (as if the apparatus was in free fall). The energy used to liberate the electrons from the cathode oriented from the back of the tube towards the front determines of course, the velocity of the 5 beams:

$$E_A\vec{k} = E_B\vec{k} = E_C\vec{k} = E_D\vec{k} = E_E\vec{k}$$

The second front view shows the beams directly aligned at the center of their respective targets after the guiding magnetic fields have been adjusted to exactly counteract the effect of local gravity. This configuration amounts to perfect calibration of the device at the location where it is going to be used. In this configuration, beams A and B are of particular interest since the two magnetic deflection corrections being applied to them are exactly normal to each other, lateral deflection exactly parallel to the x axis and vertical deflection exactly parallel to the y axis, which simplifies calculations.

So from the energy level adjustment of the various fields required to perfectly align the beams on the targets, it becomes possible to calculate the exact rest mass of the electron by subtracting the relativistic component due to its velocity and that due to the gyroradius of their deflection.

An appropriate amplification of the energy allowing these calculations would then allow very precise calibration of specially designed balances anywhere in the world without reference to the local gravity field from the behavior of a particle whose rest reference mass is universally invariant.

The energy levels observed for beams C and D at various locations would no doubt allow gathering interesting extra data regarding the gravity field in the Earth environment, since the magnetic correction that must be applied vertically parallel to the y axis will by definition be slightly less for beam C, located above beam D in the gravity field gradient.

1.4 Confirming Experiment

If the rest mass of nucleons (mostly made up of relativistic mass as was put in perspective in Section 1.2) making up the nuclei of atoms really varies by adiabatic interaction in relation to the local intensity of gravity, then obviously any increase in local gravity intensity will cause nucleons to adiabatically dilate as the velocity of the captive quarks determining their volume diminishes, thus decreasing the relativistic fraction of their rest masses, while any local decrease in gravity intensity will cause them to adiabatically contract thus increasing the relativistic fraction of their rest mass.

This means that less densely packed nuclei such as those of lithium or magnesium for example would have a nucleon contraction gradient towards maximum density as local gravity intensity decreases that would be more pronounced than that of denser elements, such as uranium or osmium, given that they contain much fewer nucleons in volumes of about the same order (The diameter of denser atoms, including electronic escorts being estimated at only about 3 times that of hydrogen, so the ratio between lightest and densest metals will be lower yet), meaning that the nucleons of less dense elements should contract more rapidly than those of denser elements towards their limit as they are lifted in altitude away from the surface of the Earth.

A rather simple experiment could then be carried out to confirm (or invalidate) the possibility. To conduct such an experiment, only an equal-arm balance would be required with which two masses of widely different densities would be set in perfect equilibrium at ground level, or better yet, at the bottom of the deepest mine shaft possible, and that this assembly then be lifted in altitude.

Why not 10 km, as was done with the first caesium atomic clocks? If the nucleons contraction gradients really are different for low and high density elements, then the side holding the low density element should go down as altitude increases, showing that the less dense element is now becoming more massive than the higher density element, both of which would have had exactly the same measured mass when first put in equilibrium at the beginning of the experiment at ground level or at the bottom of a deep mine shaft.

1.5 References

[1] Lide DR, Editor-in-chief (2003). **CRC Handbook of Chemistry and Physics.** 84th Edition 2003-2004, CRC Press, New York.

[2] **National institute of Standards and Technology, (NIST),** (February 2011).

[3] **International Bureau of Weights and Measures.**

[4] Andreas B, Azuma Y. et al. (2010) **An accurate determination of the Avogadro constant by counting the atoms in a 28Si crystal**.

[5] **NIST Backs Proposal for a Revamped System of Measurement Units**.

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