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Tribunes

UNITS AND CONSTANTS

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How heavy is a kilogram?

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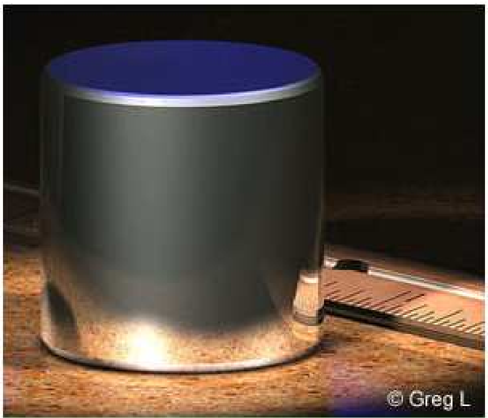

A computer generated image of the standard international kilogram

Human culture is full of references essential for effective communication. A classic example is the use of language. When you say *cama*, for example, Catalan speakers associate it with one of our lower extremities (a leg). It is an arbitrary reference, however, because if the person is a Spanish speaker, he or she will no doubt associate the same word with a piece of furniture designed for sleeping (a bed), while in many other languages *cama* does not mean anything at all.

While we all accept that in the case of languages each culture has developed its own system of references, in mathematics, and even more so with units of measurement, the need for a common system to establish universal units, units that must be immutable, has long been clear. But sometimes things we take to be simple are actually quite complex, an illusion recently highlighted in the case of the kilogram. For example, are we sure what we really get when we ask the shopkeeper for a kilo of apples? An article published in the journal *Nature* raises serious doubts that the answer may not be as clear cut as most of us assume, at least on a physical level.

But let's start with a short history lesson, because units of measure have not always been universal. Formerly in Catalonia, a "measure" of a given product varied according to region and also according to what was being measured. For instance, a measure of grain worked out to be the rough equivalent to about 18 of today's liters, with the measure suffering minor variations region to region: in Girona it would be the equivalent to 18.08 liters, in Lleida 18.34 liters, in Roussillon 18.69 liters, etc. In contrast, a measure of olives was more or less equivalent to 20 liters in many of these areas. This system seems odd to us now because we quantify grain and olives by weight, not by volume. But the measure also was used to quantify volume of liquids. For example, in the wine region of the Penedès, a measure of wine was the equivalent of about 8 of today's liters, while in Mallorca one measure was almost double: 16 liters.

Common measurement systems

The first set of common measurements accepted by various countries was the so-called metric system, which was proposed by a group of scientists who had been commissioned by King Louis XVI of France to create a unified and rational set of measurements. Thus arose a universal mass unit, the kilogram, which was defined as the mass of a liter of water about to reach its freezing point. The unit chosen for length was the meter, defined as the ten-millionth part of a quarter of the Earth's meridian. And time was divided by the second, defined in terms of the planet's rotation.

For both the meter and the kilogram, theoretically immutable standards were created for reference. The standard kilogram was forged 131 years ago in London, in the form of a cylinder of platinum and iridium of 39 mm in length that accurately reproduces the mass of a liter of water. Both the standard kilogram as well as the standard meter (a bar made from the same materials so that it would not be affected by temperature changes) are carefully kept in the armored basement of the International Bureau of Weights and Measures in Sèvres, France.

However, in 1960, during the celebration of the 11th General Conference of Weights and Measures, held in Paris, an evolution of the metric system, called the International System of Units (abbreviated SI from its French name), was adopted. The SI is currently used around the world in both science and in everyday life, except in the United States, Australia and Myanmar. The SI, in addition to the units of mass, length and time, has also over time incorporated the ampere (unit of electrical current), the kelvin (unit of temperature), candela (unit of light) and mole (unit of the amount of substance) as standard units of measure.

The scientific advances of recent years make it necessary to redefine the International System of Units

Why is this important? Because during the past decades the advancement of science in general and particularly in physics, along with the increasing sophistication and precision of measuring instruments, has highlighted the urgent need to redefine many of these SI units. For example, the meter is no longer determined in relation to the Earth's meridian since the meridian can undergo subtle changes due to the dynamic geology of the planet and because the Earth is not a perfect sphere. Now we define the meter as the length that light travels in vacuum during a 299.792.458th of a second because the speed of light in a vacuum is an immutable universal constant. Similarly with time, the second now is defined as the duration of 9,192,631,770 periods of radiation corresponding to the transition between two hyperfine levels of the ground state of the Cesium-133 atom, a much more precise unit than the traditional one.

The Kilogram no longer weighs a kilogram!

The kilogram, on the other hand, continues to be the mass of the platinum-iridium prototype kept at the International Bureau of Weights and Measures in Sèvres, making it the only basic unit of measure still defined in relation to an object. Every year, like a spy movie, three people go down into the basement which houses the standard kilogram and verify that it is, indeed, still intact. Thee three individuals are the director of the bureau office, the president of the International Committee of Weights and Measures and the Director of the Archives of France, each one in exclusive custody of the three keys needed to open the basement door. And, from time to time, they weight the kilogram to ensure the immutability of this unit. There are two ways to weigh this historic kilogram. One is the so-called balance of power which measures the cylinder of platinum and iridium against Planck's constant, whose value is close, but not equal to, the weight of an electron, and which appears in all equations related to quantum mechanics.

Plank's constant and the Avogadro constant show discrepancies in the kilogram's true weight

The other way to weigh the kilogram is by using what is called the Avogadro constant, which is the number of atoms of Carbon 12 found in 12 grams of this substance. Carbon 12 is an isotope containing six protons, six neutrons and six electrons. Both Planck's constant and the Avogadro constant are immutable throughout nature, with universal application and validity, so it should be expected that they provide a completely identical reading. But no! Despite being universal constants, they produce a discrepancy of one ten-millionth part, a very small difference if we consider our daily lives, but unacceptable from the point of view of physics.

How heavy is a snowflake?

So how much does the universal standard for the kilogram actually weight? The results of the last two official weighings of the standard kilogram in 1946 and 1989 provided a disturbing result: in the 43 years between them, the standard kilogram lost 0.00005 grams. And nobody knows why.

Maybe some people think that this difference is insignificant, but 0.00005 grams (or 50 micrograms) is what a snowflake can weigh. And the weight of a snowflake is important. If you do not believe so, read this story by the German writer Kurt Kauta. Perhaps the pursuit of accuracy for the advancement of science can allow us to rethink and reconsider some of our more entrenched human conventions, such as, that within a community, one person is almost negligible.

THE STORY OF KURT KAUTA

Once a sparrow asked a dove, "How heavy is a snowflake?"
And the dove replied: "How much does it weigh? A snowflake weighs nothing."
"Nothing? Are you sure?" said the sparrow. "Listen to this story from long ago and see what you think:
One day I sat on the branch of a fir tree, just where the branch meets the trunk. After a while it began to snow, very lightly, so lightly that it hardly seemed it was snowing at all. As I had nothing else to do, I started counting, one after another, all the flakes of snow piling on top of the branch. I counted 3,741,952 snowflakes before it stopped. The next time it snowed I counted 3,741,953 very small flakes, so light they seemed to weigh nothing ... and the branch broke."
The sparrow finished his story, said goodbye to the dove and flew away.
And the dove, pondering the story of the other bird, thought to itself: "Maybe it only takes one more voice, one more effort, perhaps even my own, so that peace is possible in the world."