Stories of Science: The Kilogram; how can its definition have changed?

The story about how the kilogram is now defined in nature not a man-made object.

A quantity is something that can be measured; distance, time and temperature are all examples of differing quantities that we measure in science, and each of these quantities have their own units and unit symbols. In Science, the quantity of mass is measured in kilograms, this is the **base** unit of mass. However, on the 20th May 2019, the definition for the kilogram, alongside Ampere, Kelvin and the mole, all changed. How can the definition change? Was 1kg now equal to 1.2kg? To explain, we need to go back just over 200 years to the late 1700's and look at the history of the kilogram.

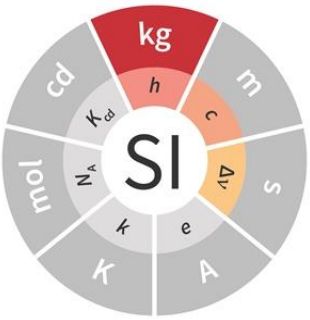

Figure 1 - SI Base Units

The flawed history of *the* kilogram

During the early years of the French Revolution, the leaders of the French National Constituent Assembly decided to introduce a new system of measurement that was based on the principles of logic and natural phenomena; The Metric System. The initial unit for mass was called the grave, defined in 1793, however this was replaced within three years with the kilogram, the kilogram, was provisionally defined in 1795 as the mass of one litre of water at the temperature of melting ice. This was a simple definition, but hard to replicate precisely. So in 1799, the Kilogramme des Archives, a platinum artefact the same mass of one litre of water, replaced it as the standard of mass.


Figure 2 – IPK aka Big K

This was replaced eighty years later in 1879 with a cylinder of platinum-iridium alloy, the International Prototype of the Kilogram (IPK a.k.a. Big K, or Le Grand K) became the standard of the unit of mass for the metric system. For more than a century since then, the kilogram had a very simple definition. It was the mass of the cylinder of platinum-iridium alloy that's been housed at the International Bureau of Weights and Measures in France. It has many copies around the world that are used to calibrate scales and make sure the whole world uses the same system of measurement. These copies ensure a kilogram is a kilogram — whether its being measured on the factory floor of an airplane maker, or on the digital scale at your grocer's checkout counter.

The problem is that Big K is a manmade object and is therefore, imperfect. If Big K changes, everything else has to adjust, and it has changed! Big K is not constant. It has lost around 50 micrograms (about the mass of an eyelash) since it was created. However, frustratingly, when Big K loses mass, it is by definition, still exactly one kilogram, per the old definition. So have masses for a kilogram been wrong for a number of years? Technically yes. That's no good. So what's better?

Anchoring the kilogram in nature.

From the 20th May 2019, the definition of one kilogram changed. Instead of being defined by a manmade object, the kilogram will be defined by the Planck constant. The Planck constant is a concept in quantum mechanics (the study of how the tiniest components of the universe works), which describes how the tiniest bits of matter release energy in discrete steps/chunks called quanta. What's important about the Planck constant is that it can never, ever change. That makes it a worthy concept to anchor the definition of the kilogram to.

Written out, the Planck constant is $6.62607015 \times 10^{-34}$ m^2 kg/s. You can treat the units of this number — meters squared times kilograms all divided by seconds — as an equation.

$$Kilogram = \frac{speed\ of\ light^2}{Planck\ constant\ \times transition\ frequency\ of\ Caesium}$$

Every unit in the Planck constant is defined by an unchanging force of nature. The metre is defined by the speed of light. The second is defined by characteristics of the atoms in the element caesium, and the value of the Planck constant was measured and agreed upon, because of years of work in measuring it to a precise degree.

Don't worry: The new kilogram has the same mass as the old kilogram. Your mass hasn't suddenly changed as a result of the new definition. It's just that we'll no longer need a government or an international governing body to tell us what a kilogram is. It will be a fundamental truth of the universe, available to anyone with the proper equipment to realize it.

Comprehension and Reflection Questions

1. What are the units you have used for Distance, Time and Temperature?

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2. Which one of those unit do you not see on the SI units wheel (figure 1)?

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3. Which widely used measuring system was proposed during the French revolution?

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4. A platinum artefact was created to measure the kilogram, what caused this to be made?

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5. What are the symbols on the periodic table for Platinum and Iridium?

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6. What is an alloy?

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7. Explain why scientists decided to come up with a new definition for a kilogram?

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8. The Big K has been very carefully looked after for many years. How do you think it has still lost 50 micrograms over this time?

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9. What is 1 kilogram written in grams

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10. What is 1 kilogram in grams as standard form?

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11. What is 1 microgram in grams as standard form?

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12. What % error was there in the Big K after 50 micrograms were lost from it?

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Extension Activities

Ideas for things to do next:

Research the unit "The Kelvin" and the reason why it's the base unit for Temperature rather than degree Celsius scale.

Apart from Ampere, Planck's and Kelvin. Can you find and name 10 other units named after a scientist.

Research the Kelvin, Ampere or mole whose definitions also changed in May 2019.

Further Reading

Ideas for things to read next:

Kilogram, ampere, kelvin and mole redefined: https://www.sciencedaily.com/releases/2018/11/181116115556.htm

The Kelvin: https://www.lgcgroup.com/newsroom-and-blog/blogs/counting-down-to-the-si-redefinition-kelvin-and-degree-celsius/

Storm in a Teacup| Helen Czerski | 2017 | 978-1784160753

How to Teach Quantum Physics to Your Dog | Chad Orzel | 2010 | 978-1851687794