Mass

The kilogram is the SI unit for measuring mass. It is the last remaining base unit to be defined as a physical object rather than in terms of a naturally occurring constant in the way that the metre is related to the speed of light. All standards of mass must ultimately be traceable to this one object. But as science and industry's requirement for a more accurate way to measure extreme weights increases, the search is on for a definition of the kilogram in terms of a fundamental constant so that it can be measured with greater accuracy and can be realised by other standards laboratories.

The history of the kilogram

In 1790 Louis XVI of France commissioned French scientists to recommend a consistent system for weights and measures. On 19th March 1791 a new system of units was recommended to the French Academy of Sciences including a unit which was the mass of a declared volume of distilled water in vacuo at the freezing point. These units were based on natural constants but were not reproducible enough for the needs of today.


The UK Kilogram 18 in its storage unit.

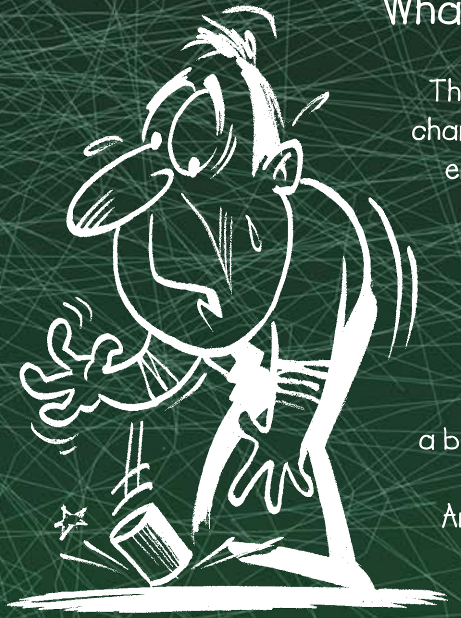
Over the next hundred years this definition of a mass unit was refined and a number of weights were manufactured to have a mass equal to it. In 1879 Johnson Matthey and Co. of London successfully cast an ingot of an alloy of platinum and iridium, a very stable material. The water definition was abandoned and the platinum-iridium weight became the standard kilogram (known as the international prototype of the kilogram K).

In 1889 forty copies of the kilogram K were commissioned and distributed to the major national standards laboratories to be their primary standard and the UK received Kilogram 18 which is now held at the National Physical Laboratory.

The definition of the kilogram

The kilogram (kg) is equal to the mass of the international prototype of the kilogram.

K, the international prototype of the kilogram is made of an alloy of platinum (90%) and iridium (10%) and is kept at the International Bureau of Weights and Measures (BIPM) in France.
K is used to calibrate all the weights in the world.



What's wrong with a physical object?

The main problem with a physical object is that its mass could change due to loss of material or contamination from the surrounding environment. K's mass could be slightly greater or less today than it was when it was made in 1884 but there is no way of proving this.

It is also possible that an object could be lost or damaged. In reality K is so carefully looked after that this is unlikely. The UK copy is in a filtered chamber to keep it clean, and is locked away in a bomb proof safe.

Another problem is the effort it takes to maintain a traceable chain between, for example, your bathroom scales and Kilogram 18.

In search of a fundamental definition of the kilogram

The search is on in a number of scientific laboratories to try to find a way of defining the kilogram in terms of a fundamental constant. Today two key approaches are being pursued:

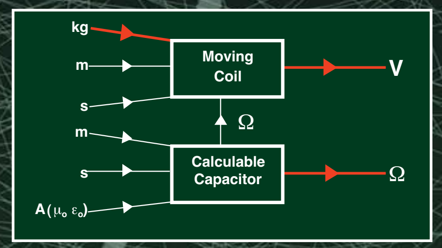
* building an electrical kilogram
* counting atoms


The electrical realisation of the kilogram at NPL.

The electrical kilogram

The quantum electrical standards for voltage and resistance, which are based upon Planck's constant and the charge on an electron, are more stable than the present kilogram. The kilogram can be accurately compared with these standards using a moving-coil apparatus described below:

Hang a 1 kg mass and a current-carrying coil in a magnetic field from a balance. Measure the electric current required to produce an electromagnetic force equal to the gravitational force acting on the mass. In this manner, the kilogram might be defined as the mass that can be suspended by the electromagnetic force generated when a specified amount of current flows.



The limitation of this is that the relationship between the current and force depends on the strength of the magnetic field and the geometry of the coil, and neither of these can be determined with sufficient accuracy. The way to overcome this is to move the coil through the field at a constant speed. This generates a voltage which depends on the same parameters as the first measurement and so the effect of magnetic field and geometry can be cancelled out in the final result.

Counting atoms

This approach relates the kilogram to an atomic mass, so that it can be defined as the mass of a fixed number of atoms of silicon. The number of atoms in a perfect silicon crystal can be counted by measuring its volume and dividing this by the volume a single atom occupies. This volume is measured by combined X-ray and optical interference techniques. This process amounts to a very accurate measurement of the Avogadro constant N_A.

The Avogadro constant N_A is defined as the number of atoms in 0.012 kg of the isotope carbon 12 and thus is the number of entities in a mole of substance.

These methods can only be used to measure the base unit if they can measure exactly one kilogram on demand. The first step is getting the resolution. This has been achieved for the electrical method. The next step is to get repeatable results and the final step is to ensure that the apparatus, procedure and results can be duplicated in other laboratories. Both the electrical kilogram researchers and the atom counters are pursuing the ultimate target of measuring a kilogram with an accuracy of a millionth of one percent every time.

NPL - the national standards laboratory

NPL maintains the national primary standards in accordance with international agreements and undertakes leading-edge research to develop and improve these standards.

The spectrum of mass

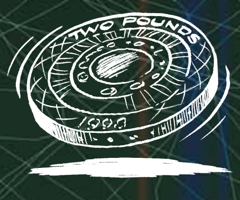
Mass of Sun = 2×10^{30} kg
2 000 000 000 000 000 000 000 000 000 000 kg

Eiffel Tower
7 112 tonnes 7 112 000 kg

African Elephant 7 500 kg

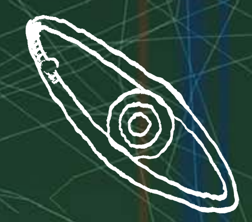
Heaviest recorded Man 635 kg

Bag of sugar 1 kg



£2 coin 11.88 g 0.01188 kg

Paper clip
0.39 g 0.00039 kg



Mass of hydrogen atom = 1.67×10^{-27} kg
0.000 000 000 000 000 000 000 000 001 67 kg

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