THE EXACT MASS OF A KILOGRAM: AVOGADRO'S CONSTANT

Avogadro's constant is named after the Italian scientist Amedeo Avogadro.
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In 2011, the International Committee for Weights and Measures formalised an approach to redefine the kilogram in terms of Planck's constant. However, this is not the only constant in nature that can be used to arrive at a more accurate definition of the kilogram. Another one that could be used for the same purpose is the Avogadro's constant.

The Avogradro's constant (denoted as N_A) is named after Amedeo Avogadro – an Italian scientist who is most well-known for his contributions to molecular theory. This constant represents the number of atoms contained in one mole of any substance. It's defined as the number of carbon-12 atoms in 12 grams of the element = 6.022×10^{23}. This quantity of carbon-12 constitutes 1 mole of the element. This is also true of every other element –1 mole of any element consists of 6.022×10^{23} of its atoms.

Since the definition of N_A is related to the mass of a substance, this constant can be used to arrive at a more precise definition of the kilogram. To do this, however, a more precise measurement of N_A would be needed – a goal that members of a worldwide collaboration called the International Avogadro Project have been working towards for more than two decades.

Have we succeeded in getting a more precise value of Avogadro's constant? Find out on page 88.

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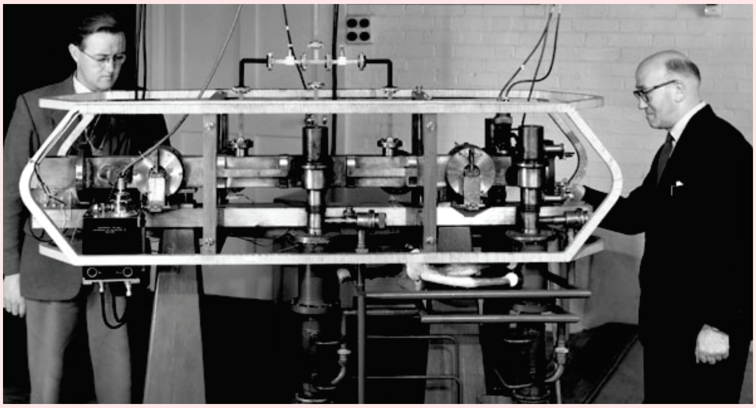
WONDER WHAT THE EXACT TIME IS?

Our lives today are hugely dependent on accurate time measurements. But, have you ever wondered how time is measured exactly to several decimals of a second?

From age-old methods using celestial, then mechanical, and quartz crystal-based measurements, we have progressed to measuring time using the properties of atoms. When excited with a suitable energy source, electrons of atoms accept and release energy to oscillate between lower and higher energy levels at a constant rate. Since this property, known as their resonance frequency, is constant for atoms of a particular element, it can be used for accurate time measurement.

The adoption of a caesium atom based clock for official measurements of time across the world since the 1960's has ensured precision and accuracy. Caesium (Cs), in Group I of the Periodic Table of Elements has only one electron in its outermost shell. When exposed to intense microwave radiation, this electron in each caesium atom first jumps to a higher energy state and then returns to its original state, emitting photons in the process. Being an atomic property, the duration of each cycle of jumping up and down energy levels is a constant, or takes the exact same amount of time. This is extremely short, though, with an electron completing 9,192,631,770 cycles every second, expressed as Hz or cycles per second. Based on this standard, the International System of Units (SI) has defined one second as the duration of 9,192,631,770 cycles of radiation corresponding to the transition between two energy levels of the caesium-133 atom.



Most countries have installed their own atomic clocks to keep track of this standard time. India's standard clock is located at The National Physical Laboratory, New Delhi.

Louis Essen and J. V. L. Parry standing next to the world's first caesium atomic clock, developed at the UK National Physical Laboratory in 1955.

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THE EXACT MASS OF A KILOGRAM: COUNTING ATOMS

For more than two decades, members of the International Avogadro Project have been working towards obtaining a more precise (with an error margin of just 20 parts per billion) measurement of Avogadro's constant (denoted as N_A). This project involves researchers at INRiM in Italy, PTB in Germany, NIM in China, METAS in Switzerland, NMIJ in Japan, BIPM in France, NIST in the U.S., and IRMM in Belgium.

These researchers use 94 mm reflective spheres/balls composed of exactly one kilogram of highly enriched (99.9995%) silicon-28 to calculate:

1. The volume of each ball by using a device called an optical interferometer to measure its width (to nanometre precision).
2. The volume of a single atom in the ball by using a technique called X-ray crystallography to measure the volume of a single cubic cell.

The ratio of the volume of the ball to that of one of its atoms provides an estimate of the total number of atoms in the ball.

While N_A is defined in terms of carbon-12, silicon has a special property – it crystallizes into a lattice, with every cubic cell consisting of eight atoms, and each atom taking up exactly the same volume of space. Enrichment helps minimise the presence of isotopes of silicon, ensuring that most atoms in the ball occupy exactly the same space. The smoothness of the ball's surface minimises errors in measurement. Crafted by a master lens maker, this ball may be the 'world's roundest' object!

The world's roundest object?

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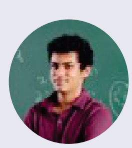
Researchers from the Avogadro project have refined this method to arrive at a value for Avogadro's constant (N_A = 6.02214076 x 10^{23} mol^{-1}) with an uncertainty of just 10 parts per billion. Since it is defined in terms of the mass of a substance, a more precise measurement of this constant could be used to redefine the kilogram. Avogadro's constant is also related to and dependent on Planck's constant. As a result, the re-defined N_A was used to arrive at four measurements of Planck's constant with error margins that were no more than +/- 0.000000020 (or an uncertainty of 20 parts per billion). This satisfied part of the criteria outlined by the International Committee for Weights and Measures.

Have we managed to meet the other criteria listed out by the International Committee for Weights and Measures? Find out on page 93.



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