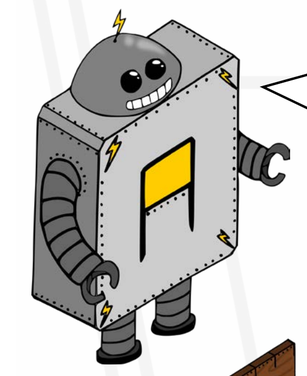
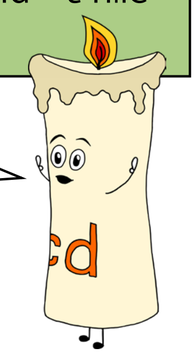
The SI and the constants of nature

The fundamental physical constants are quantities that are both universal in nature (in other words identical throughout the universe) and are unchanging with time. These constants are a consequence of the fundamental theories of physics and may be measured with great precision nowadays.



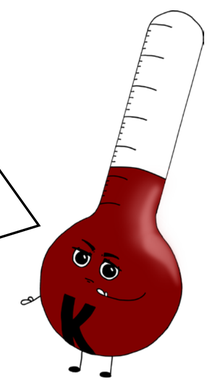
Wow, so the laws of the natural universe are the same everywhere?

The fundamental constants underpin all of science by providing scale to the physical laws of the universe. Experiments can be designed to confirm theoretical models of physics which describe the way in which nature works. It is amazing that scientists have been able to make measurements across the length and time scales of the universe.

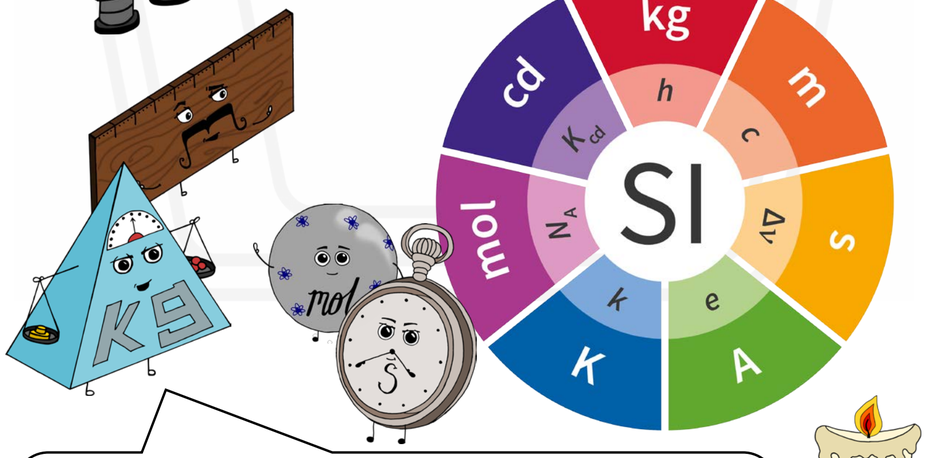


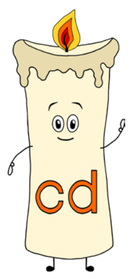
Do you mean that experiments are the key to science?

Yes, no matter how clever you are, or how important you are, or how fancy your ideas are about the way nature works, if your ideas are not supported by the measurement results from experiment then they are wrong. It's as simple as that. That is the way science works. The relationship between experiment (observation and measurement) and ideas (theories) is critical.

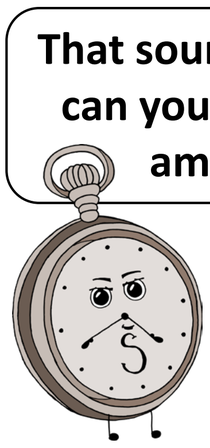


We heard that the SI have been redefined in terms of fundamental constants. How does that work?





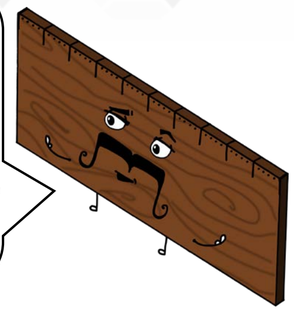
First you need to be able to measure the fundamental constants precisely. As they are universal and unchanging, every measurement in every laboratory in the world, or on the moon, or even in another galaxy will give consistent results. Seven fundamental constants have been chosen and are linked to the seven base SI units as shown in the table. Once you can realise the seven SI base units through experiment, then every single quantity in measurement has traceability to the SI.



That sounds confusing… can you explain how I am defined?

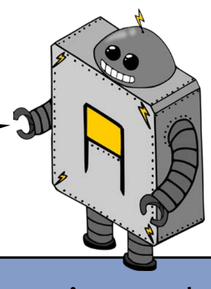
$\Delta\nu(^{133}\mathrm{Cs}) = 9\ 192\ 631\ 770\ \mathbf{s}^{-1}$ (Hz) unperturbed ground state hyperfine transition frequency of the caesium-133 atom	The transition of an electron between energy levels in a ^{133}Cs atom emits radiation with this unique frequency.
$c = 299\ 792\ 458\ \mathbf{m}\ \mathrm{s}^{-1}$ speed of light in vacuum	The ultimate speed limit! This is the maximum speed at which all conventional matter can travel.
$h = 6.626\ 070\ 15 \times 10^{-34}\ \mathbf{kg}\ \mathrm{m}^2\ \mathrm{s}^{-1}$ (J s) Planck constant	Relates the energy carried by a photon to its frequency.
$k = 1.380\ 649 \times 10^{-23}\ \mathrm{kg}\ \mathrm{m}^2\ \mathbf{K}^{-1}\ \mathrm{s}^{-2}$ (J K^{-1}) Boltzmann constant	Relates the average kinetic energy of molecules in a gas to its temperature.
$e = 1.602\ 176\ 634 \times 10^{-19}\ \mathbf{A}$ s (C) elementary charge	The magnitude of the electric charge carried by a single electron.
$K_{cd} = 683\ \mathbf{cd}\ \mathrm{kg}^{-1}\ \mathrm{m}^{-2}\ \mathrm{s}^3$ (lm/W) luminous efficacy of monochromatic radiation of frequency 540×10^{12} Hz	Describes exactly how bright a source of light is for a specific frequency (or colour) and power.
$N_A = 6.022\ 140\ 76 \times 10^{23}\ \mathbf{mol}^{-1}$ Avogadro constant	The number of particles (atoms, molecules, objects, etc.) in one mole of any substance.

Does that mean that I rely on the second to be defined?



Atomic energy levels are fixed by the configuration of individual atoms and are unique for every isotope. One particular configuration has been chosen as the defining constant for the second as it can be measured to high precision. The transition frequency of the caesium-133 atom $\Delta\nu(^{133}\mathrm{Cs})$ is known to be 9192631770 Hz, i.e. per second.

For the metre, the speed of light in a vacuum c is used. The metre is then defined as the length of the path travelled by light in vacuum during a time interval of 1/299792458 seconds. The definition of the second is then used from its constant $\Delta\nu(^{133}\mathrm{Cs})$, in combination with the speed of light c, to realise the metre.



Each of the seven SI base units is thus constructed from one or more of the seven constants.

No matter where scientists are from or what language they speak, physics is defined and communicated by a set of mathematical principles, physical theories, and base units defined by nature itself!

nmisa
National Metrology Institute of South Africa

MeASURe
Metrological and Applied Sciences University Research Unit

DEPARTMENT OF PHYSICS
UNIVERSITY OF CAPE TOWN