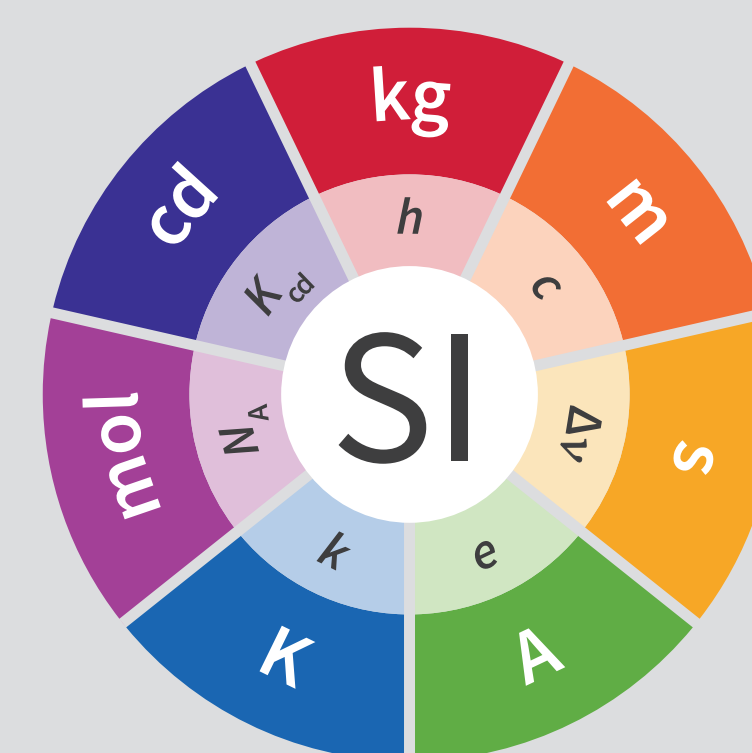# 7 SI BASE UNITS

Everything can be measured in terms of the SI base units.

MASS kilogram — kg

The kilogram is defined by taking the fixed numerical value of the **Planck constant** h to be **6.626 070 15 × 10⁻³⁴** when expressed in the unit J s, which is equal to kg m² s⁻¹, where the metre and the second are defined in terms of c and Δv.

We compare the gravitational force on an object against an electromagnetic force, using an instrument known as a 'Kibble balance'.

LENGTH metre — m

The metre is defined by taking the fixed numerical value of the **speed of light in vacuum c** to be **299 792 458** when expressed in the unit m s⁻¹, where the second is defined in terms of the caesium frequency Δv.

The speed of light is a universal constant of nature, making it ideal as a length standard. At NPL, traceability to the metre is most commonly achieved using the wavelength of the 633 nm radiation from an iodine-stabilised helium-neon laser, with an uncertainty of about 2 parts in 10¹¹. This is equivalent to measuring the Earth's mean circumference to about 1 mm.
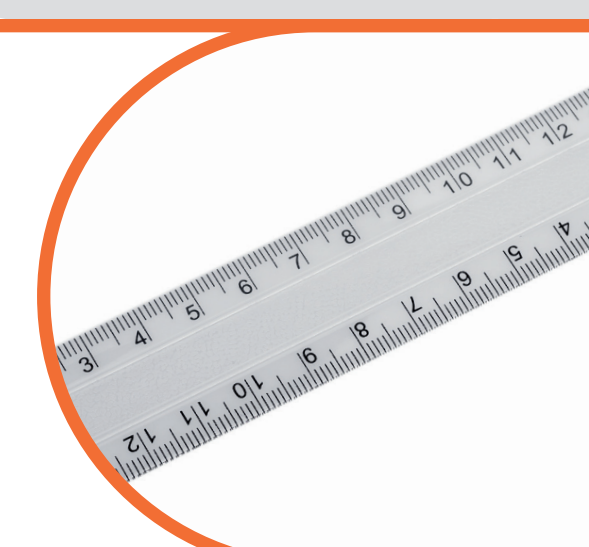
TIME second — s

The duration of **9 192 631 770** oscillations of the radiation corresponding to the transition between two energy levels of the caesium atom.

NPL built the world's first accurate atomic clock in 1955 and paved the way for a new definition of the second based on the caesium 133 atom. NPL's atomic clocks help the UK run on time by disseminating the national time scale and by contributing to Coordinated Universal Time (UTC).

ELECTRICITY ampere — A

The ampere, symbol A, is the SI unit of electric current. It is defined by taking the fixed numerical value of the **elementary charge e** to be **1.602 176 634 × 10⁻¹⁹** when expressed in the unit C, which is equal to A s, where the second is defined in terms of Δv.

TEMPERATURE kelvin — K

The kelvin is the SI unit of thermodynamic temperature. It is defined by taking the fixed numerical value of the **Boltzmann constant k** to be **1.380 649 × 10⁻²³** when expressed in the unit J K⁻¹, which is equal to kg m² s⁻² K⁻¹, where the kilogram, metre and second are defined in terms of h, c and Δv.

Unusually in the SI, we also define a second unit of temperature called the degree Celsius (°C). This is related to the kelvin by subtracting 273.15 from the numerical value of the temperature expressed in kelvin.

AMOUNT OF SUBSTANCE mole — mol

One mole contains exactly **6.022 140 76 × 10²³** elementary entities. This number is the fixed numerical value of the **Avogadro constant, N_A**, when expressed in the unit mol⁻¹ and is called the 'Avogadro number'. An elementary entity may be an atom, a molecule, an ion, an electron, any other particle or specified group of particles.

Most chemical measurements require the determination of the composition of mixtures, rather than the absolute amount of substance present, for example the concentration of lead in drinking water.

LUMINOUS INTENSITY candela — cd

The candela, symbol cd, is the SI unit of luminous intensity in a given direction. It is defined by taking the fixed numerical value of the **luminous efficacy of monochromatic radiation of frequency 540 × 10¹² Hz, K_{cd}**, to be **683** when expressed in the unit lm W⁻¹, which is equal to cd sr W⁻¹, or cd sr kg⁻¹ m⁻² s³, where the kilogram, metre and second are defined in terms of h, c and Δv.

At NPL, the candela is realised using the cryogenic absolute radiometer, which heats a black cavity first with a laser beam, and then with electricity. This measures the optical power in the laser beam, which is then used to calibrate a photometer, a detector with a filter to mimic the spectral response of the human eye.

Did you know?

Historically, base units were defined in terms of objects. Now we use physical constants whose value will not change. Each base unit is related to one or more of these constants. In the UK, the International System (SI) base units are realised at the National Physical Laboratory (NPL).

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