Traceability of all the measurements is established, through periodic calibrations, to the National Standards of Measurements, maintained at NPL and ultimately to the SI units. The accuracy of all measuring instruments used by educational, scientific /technical institutions, industrial establishments and other organizations is ascertained by these periodic calibrations which is essential for 'Quality Control' of all products and processes for consumer protection and for international trade and commerce.

NATIONAL PHYSICAL LABORATORY

(Council of Scientific and Industrial Research)

NEW DELHI - 110012, INDIA

SI UNITS OF MEASUREMENT

This poster describes the base units in the International System (SI) and lists also a number of units derived from them, all of which are part of a coherent measurement system. In a coherent system calculations involving a number of quantities may be made and the correct result is obtained without the introduction of arbitrary constants. The base units and a number of the derived units are the legal units of measurement of the relevant quantities in India.

Quantity, Unit, Symbol and Definition

Realization of Units and National Standards at NPL, India

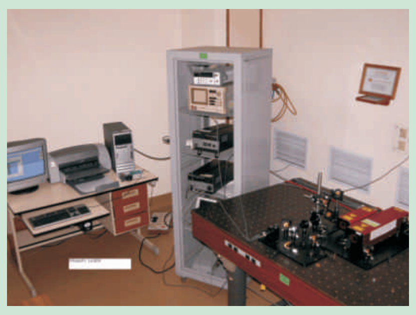
Length : metre (m)

The metre is the length of the path travelled by light in vacuum during a time interval of 1/299 792 458 of a second.

The SI unit 'metre' is realized as per recommendations of BIPM for practical realization of the unit 'metre'.

An Iodine ($^{127}I_2$) frequency stabilized He-Ne Laser is maintained as per BIPM recommendations. This is the primary optical frequency standard. The frequency of this radiation (stabilized w.r.t. f component) is 473612353604.1 kHz and the corresponding vacuum wavelength is 632.99121258 nm with overall uncertainty in measurement $< 2 \times 10^{-11}$ (k=1)*

Laser interferometers, calibrated for their frequency against the above mentioned primary standard, are used to transfer traceability to length measurements.



Mass : kilogram (kg)

The 'kilogram' is the unit of mass; it is equal to the mass of the international prototype of the kilogram.

This international prototype is made of platinum iridium and is kept at the International Bureau of Weights and Measures, Serves, Paris, France.

India has copy 57 of the international prototype kilogram, which serves as its primary standards.

Multiple and submultiple of 1 kg, ranging from 1 mg to 2000 kg are calibrated against the national prototype kilogram using precision balance with measurement uncertainty ranging from 2 μg to 10 g (k=2)*

Time : second (s)

The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium-133 atom.

The second is realized by an ensemble of five cesium beam frequency standards with an uncertainty of 7 ns. The time scale of NPL, designated as UTC (NPLI), is linked to the internationally maintained time scale UTC through GPS network.

Electric current: ampere (A)

The 'ampere' is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross section, and placed 1 metre apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per metre of length.

The ampere is based on the volt and the ohm with an overall relative uncertainty $\pm\ 2.10^{-6}$ (k=2)*. The 'volt' is maintained in the form of standard cells/Zener based voltage reference standard traceable to Josephson series array voltage standard at 1 V and 10 V levels established at NPLI. The 'ohm' is maintained in form of a bank of standard resistor at 1 Ω. These are traceable to Quantum Hall Resistance standard (QHR) established at NPLI.

Thermodynamic temperature : kelvin (K)

The 'kelvin,' unit of thermodynamic temperature, is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water.

The triple point of water is realized with an uncertainty of 0.17 mK (k=2)* in cells similar to the one illustrated here. Practical temperature in the range 84 K to 2500 K can be measured with appropriate uncertainties throughout this range of temperature. Calibration can be done of all temperature-measuring instruments in this range.

Luminous intensity : candela (cd)

The 'candela' is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} hertz and that has a radiant intensity in that direction of 1/683 watt per steradian.

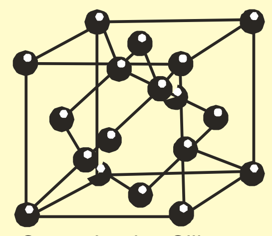
The standards of luminous intensity is maintained through a set of incandescent lamps traceable to international standards. The range covered is 1 cd to 1000 cd at 2856 K. Uncertainty in the measurement is in the range of ± 1.6 % to 1.4 % (k=2)*. Radiometric measurement have shown that 1cd is equivalent to 1/682 watt per steradian.

Amount of substance : mole (mol)

The 'mole' is the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kilogram of carbon 12.

When the 'mole' is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles.

The mole is not realized directly from its definition. It can be realized in various indirect ways. The related Avogadro constant, the number of elementary entities for silicon per mole is now known to have an uncertainty in silicon molar mass of about a part in a million.



Space Lattice Silicon

Avogadro Constant: $6.022\ 045 \times 10^{23}$ mol^{-1}

*k is coverage factor which corresponds to a coverage probability of approximately 95% confidence level.

Examples of SI coherent derived units in terms of base units

Derived unit	Symbol	Name	Symbol
Area	A	square metre	m^2
Volume	V	cubic metre	m^3
Speed/velocity	ν	metre per second	ms^{-1}
Acceleration	A	metre per second square	ms^{-2}
Wave number	σ,ν	reciprocal of metre	m^{-1}
Specific volume	υ	cubic metre per kilogram	m^3kg^{-1}
Mass density	ρ	kilogram per metre cube	kgm^{-3}
Current density	J	Ampere per square metre	Am^{-2}
Magnetic field strength	H	ampere per metre	Am^{-1}
Amount Concentration	C	mole per cubic metre	$molm^{-3}$
Mass concentration	ρ, γ	kilogram per metre cube	kgm^{-3}
Luminance	L_ν	candela per square metre	Cdm^{-2}
Refractive Index	n	one	1
Relative permeability	μ_r	one	1

Coherent derived units with special names

Quantity	Name	Symbol	In terms of special name	In terms of base units
Plane angle	radian	rad	---	m/m
Solid angle	steradian	sr	---	m^2/m^2
Frequency	hertz	Hz	---	s^{-1}
Force	newton	N	---	$mkgs^{-2}$
Pressure, stress	pascal	Pa	Nm^{-2}	$m^{-1}kgs^{-2}$
Energy of any kind	joule	J	Nm	$m^2 kgs^{-2}$
Power, radiant flux	watt	W	J/s	m^2kgs^{-3}
Electric charge	coulomb	C	--	As
Electric potential difference or e.m.f	volt	V	W/A	$m^2kgs^{-3}A^{-1}$
Capacitance	farad	F	C/V	$m^{-2}kg^{-1}s^4A^2$
Electric resistance	ohm	Ω	V/A	$m^2kgs^{-3}A^{-2}$
Electric conductance	siemens	S	A/V	$m^{-2}kg^{-1}s^3A^2$
Magnetic flux	weber	Wb	Vs	$m^2kgs^{-2}A^{-1}$
Magnetic flux density	tesla	T	Wb/m^2	$kgs^{-2}A^{-1}$
Inductance	henry	H	Wb/A	$m^2kgs^{-2}A^{-2}$
Celsius temperature	degree celsius(4)	ºC	---	K
Luminous flux	lumen	lm	cdsr	cd
Illuminance	lux	lx	lm/m^2	$m^{-2}cd$
Activity referred to radio - nuclide	becquerel	Bq	Bq	s^{-1}
Absorbed dose, specific energy imparted, kerma	gray	Gy	J/kg	m^2s^{-2}
Dose equivalent, Ambient dose equivalent, directional dose equivalent, personal dose equivalent	sievert	Sv	J/kg	m^2s^{-2}
Catalytic activity	katal	kat	--	$mols^{-1}$

SI derived units whose names and symbols include derived units with special names and symbols

Quantity	Name	In terms of Special names	In terms of base units
Dynamic viscosity	Pascal second	Pas	$m^{-1}kgs^{-1}$
Moment of force	Newton metre	Nm	m^2kgs^{-2}
Angular velocity	Radian per second	rad/s	s^{-1}
Angular acceleration	Radian per second square	rad/s^2	s^{-2}
Surface tension	Newton per metre	N/m	kgs^{-2}
Heat flux density, irradiance	Watt per square metre	W/m^2	kgs^{-3}
Heat capacity, entropy	Joule per kelvin	J/K	$m^2kgs^{-2}K^{-1}$
Specific heat capacity, specific entropy	Joule per kilogram kelvin	J/(kgK)	$m^2s^{-2}K^{-1}$
Specific energy	Joule per kilogram	J/kg	m^2s^{-2}
Thermal conductivity	Watt per metre kelvin	W/mK	$mkgs^{-3}K^{-1}$
Energy density	Joule per cubic metre	J/m^3	$m^{-1}kgs^{-2}$
Electric field strength	Volt/metre	V/m	$mkgs^{-3}A^{-1}$
Electric charge density	Coulomb per cubic metre	C/m^3	$m^{-3}sA$
Surface charge density	Coloumb per square metre	C/m^2	$m^{-2}sA$
Electric flux density, electric displacement	Coulomb per square metre	C/m^2	$m^{-2}sA$
Permittivity	Farad per metre	F/m	$m^{-3}kg^{-1}s^4A^2$
Permeability	Henry per metre	H/m	$mkgs^{-2}A^{-2}$
Molar energy, molar heat capacity	Joule per mole	J/mol	$m^2\ kgs^{-2}mol^{-1}$
Exposure (X and rays)	Coulomb per kg	C/kg	$kg^{-1}sA$
Absorbed dose rate	Gray per second	Gy/s	m^2s^{-3}
Radiant intensity	Watt per steradian	W/sr	m^2kgs^{-3}
Radiance	Watt per square metre steradian	W/m^2	kgs^{-3}
Catalytic (activity) concentration	Katal per cubic metre	kat/m^3	$m^{-3}s^{-1}mol$

Non-SI units accepted for use with the International System

Name	Symbol	Value in SI units
minute	min	1 min = 60 s
hour	h	1 h = 60 min = 3600 s
day	d	1 d = 24 h = 86 400 s
degree	°	1° = (π/180) rad
minute	′	1′= (1/60)° = (π/10 800) rad
second	″	1″= (1/60)′ = (π/648 000) rad
hectare	ha	$1ha = 1\ hm^2 = (100m)^2 = 10^4\ m^2$
litre	l, L	$1l = 1\ dm^3 = 10^{-3}\ m^3$
tonne	t	$1t = 10^3$ kg

Non-SI units

Quantity	Name	Symbol	Value in SI units
Pressure	bar	bar	1 bar = 0.1 MPa = 10^5 Pa
	Millimetres of mercury	mmHg	1 mmHg = 133.322 Pa
Length	Angstrom[2]	Å	1 Å = 0.1 nm = 10^{-10} m
Distance	nautical mile	M	1 M = 1852 m
Area	barn	b	1 b = 100 fm^2 = $10^{-28}\ m^2$
Speed	knot	kn	1 kn = (1852/3600) m/s
Logarithmic	Neper	(Np)	Logarithmic ratio to the base e
ratio	Bel	B	Logarithmic ratio to the base 10
sound pressure	Decible	dB	1 dB= (1/10)B

SI prefixes

Factor	Name	Symbol	Factor	Name	Symbol
10^{24}	Yotta	Y	10^{-1}	Deci	d
10^{21}	Zetta	Z	10^{-2}	Centi	c
10^{18}	Exa	E	10^{-3}	Milli	m
10^{15}	Peta	P	10^{-6}	Micro	μ
10^{12}	Tera	T	10^{-9}	Nano	n
10^{9}	Giga	G	10^{-12}	Pico	p
10^{6}	Mega	M	10^{-15}	Femto	f
10^{3}	Kilo	k	10^{-18}	Atto	a
10^{2}	Hecto	ha	10^{-21}	Zepto	z
10^{1}	Deca	da	10^{-24}	Yocto	y

Non-SI units whose values in SI units must be obtained experimentally

Quantity	Name of unit	Symbol for unit	Value in SI units
Units accepted for use with the SI			
energy	electronvolt	eV	1 eV = 1.602 176 53 (14) × 10^{-19} J
mass	dalton,	Da	1 Da = 1.660 538 86 (28) × 10^{-27} kg
	unified atomic mass unit	u	1 u = 1 Da
length	astronomical unit	ua	1 ua = 1.495 978 706 91 (6) × 10^{11}m
Natural units (n.u.)			
speed	n.u. of speed (speed of light in vacuum)	c_o	299 792 458 m/s (exact)
action	n.u. of action(reduced Planck constant)	$\hbar$	1.054 571 68 (18) × 10^{-34} J s
mass	n.u. of mass (electron mass)	m_e	9.109 3826 (16) × 10^{-31} kg
time	n.u. of time	$\hbar/(m_e c_0^2)$	1.288 088 6677 (86) × 10^{-21} s
Atomic units (a.u.)			
charge	a.u. of charge, (elementary charge)	e	1.602 176 53 (14) × 10^{-19} C
mass	a.u. of mass, (electron mass)	m_e	9.109 3826 (16) × 10^{-31} kg
action	a.u. of action, (reduced Planck constant)	$\hbar$	1.054 571 68 (18) × 10^{-34} J s
length	a.u. of length, bohr (Bohr radius)	a_0	0.529 177 2108 (18) × 10^{-10} m
energy	a.u. of energy, hartree (Hartree energy)	E_h	4.359 744 17 (75) × 10^{-18} J
time	a.u. of time	$\hbar/E_h$	2.418 884 326 505 (16) × 10^{-17} s

Numerical values of the Non-SI units are as prescribed by BIPM in 2006 Edition of The International System of Units (SI) .

Latest Values of Important Physical Constants

Quantity	Symbol	Value	unit ur
Speed of light in vacuum	c	299 792 458 ms^{-1}	exact
Magnetic constant	μ_0	$4\pi x10^{-7}\ NA^{-2}$	exact
Electric constant	ε_0	8.854 187 817…x10^{-12} Fm^{-1}	exact
Gravitation constant	G	6.67428x10^{-11} $m^3 kg^{-1}s^{-2}$	1.0x10^{-4}
Planck constant	h	6.626 068 96x10^{-34} Js	5x10^{-8}
Elementary charge	e	1.602 176 487x10^{-19} C	2.5x10^{-8}
Electron mass	m_e	9.109 38215x10^{-31} kg	5x10^{-8}
Proton mass	m_p	1.672 621 637x10^{-27} kg	5x10^{-8}
Fine structure constant	α	7.297 352 5376x10^{-3}	6.8x10^{-10}
Rydberg constant	R_∞	1.0973 731 568 527x10^7 m^{-1}	6.6x10^{-12}
Avogadro constant	N_α	6.022 14179x10^{23} mol^{-1}	5.0x10^{-8}
Molar gas constant	R	8.314 472 $Jmol^{-1}K^{-1}$	1.7x10^{-6}
Boltzmann constant	k	1.380 6504x10^{-23} JK^{-1}	1.7x10^{-6}
Electron volt	eV	1.602 176 487x10^{-19} J	2.5x10^{-8}
Atomic mass unit	u	1.660 538 782x10^{-27} kg	5.0x10^{-8}

ur means relative standard uncertainty.

Reference: CODATA-2006 published Mod. Phys. 80,633-730, 2008

Published by : **National Physical Laboratory**
Dr. K.S. Krishnan Road
New Delhi- 110012