Riferibilità

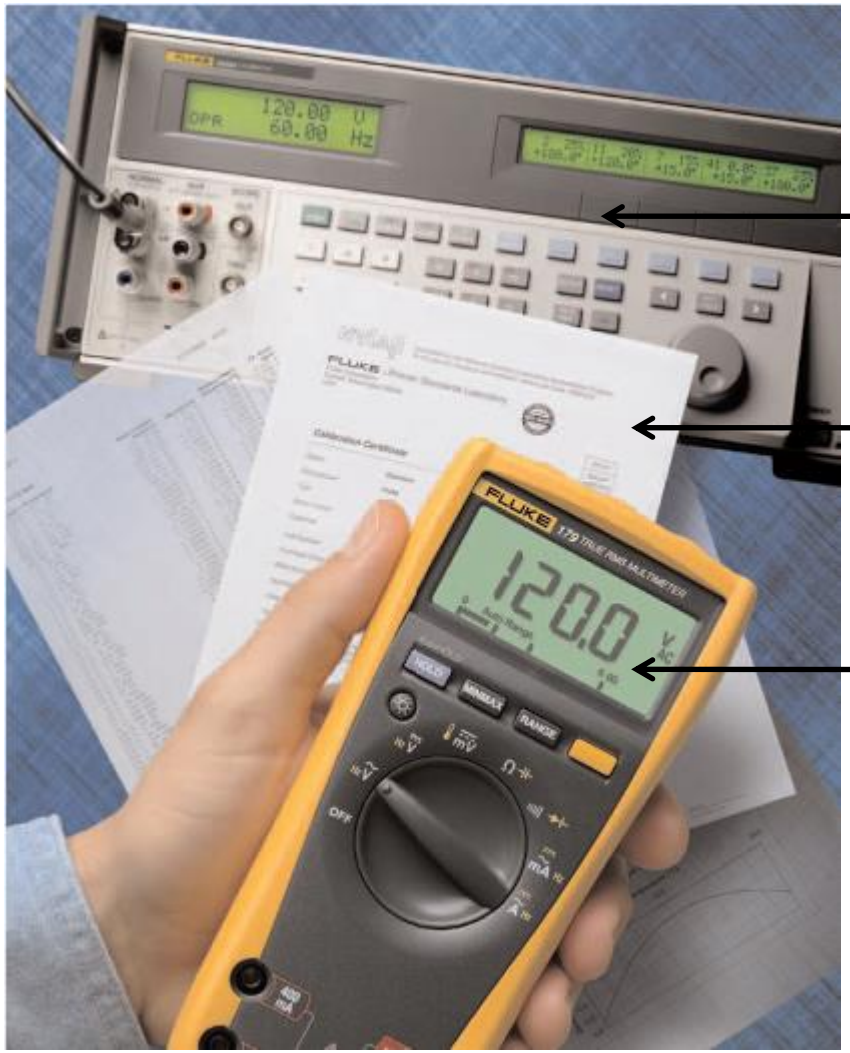
Riferibilità (*traceability*)

✓Proprietà del risultato di una misura o del valore di un campione per la quale esso può essere messo in relazione a un riferimento stabilito, generalmente un campione nazionale o internazionale, attraverso una catena ininterrotta di confronti (catena di riferibilità) aventi tutti un'incertezza determinata.

Taratura (*calibration*)

✓insieme delle operazioni che stabiliscono, sotto specificate condizioni, la relazione tra i valori di una quantità indicati da uno strumento o da un sistema di misura e i corrispondenti valori realizzati dai **campioni.**

Taratura in pratica

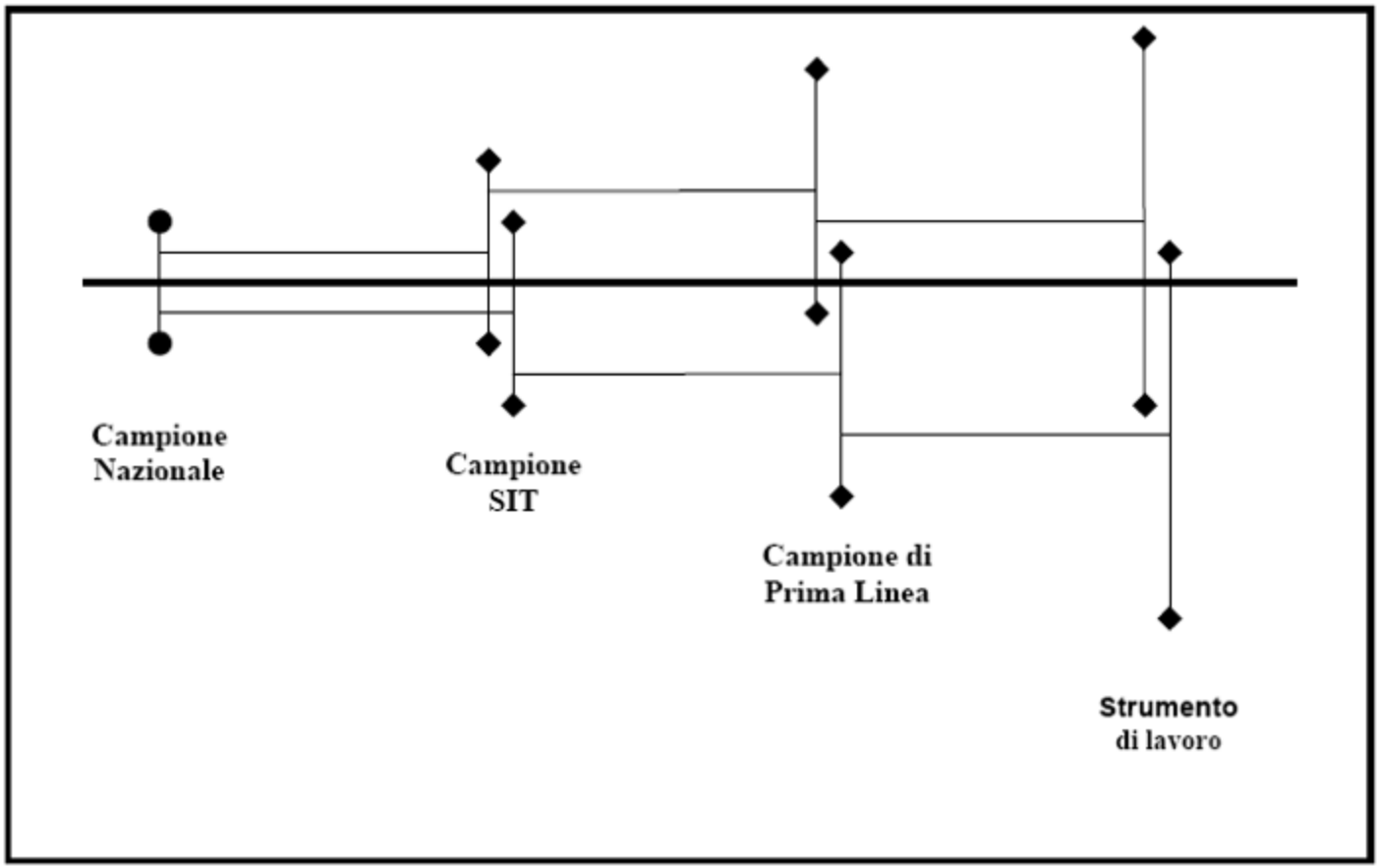


Calibratore
Riferimento di lavoro

Certificato di taratura
Documento

DUT
Dispositivo in prova

Catena di Riferibilità



La metrologia

✓*Metrologia scientifica*: si occupa dell'organizzazione e dello sviluppo dei campioni di misura e della loro conservazione (è il livello di accuratezza più elevato)

✓*Metrologia industriale*: assicura l'adeguato funzionamento degli strumenti di misura usati nell'industria tanto nella produzione quanto nelle procedure di collaudo

✓*Metrologia legale*: riguarda l'accuratezza delle misure che hanno influenza sulla trasparenza delle transazioni economiche, sulla salute e sulla sicurezza

Gli Istituti Metrologici

BIPM - (*Bureau International des Poids et Mesures*).

- ✓**INRIM** . Istituto Nazionale di Ricerca Metrologica
  - **IENGF -** Istituto Elettrotecnico Nazionale Galileo Ferraris
  - **IMGC -** Istituto di Metrologia Gustavo Colonnetti
- ✓**ENEA** - Ente per Nuove Tecnologie, l'Energia e l'Ambiente

- ✓**NIST -** *National Institute of Standards and Technology* (USA)
- ✓**PTB -** *Physikalisch-Technische Bundesanstalt* (DE)
- ✓**NPL -** *National Physical Laboratory* (UK)

Metrologia internazionale

✓**Convenzione del Metro**, stipulata a Parigi nel 1875 da parte di 17 Paesi. Oggi sono 48 i Paesi più industrializzati che aderiscono a tale trattato, il quale riveste il ruolo di un accordo diplomatico fra gli Stati firmatari.

✓Scopo fondamentale del trattato è la definizione del **Sistema Internazionale di Unità di Misura** e la sua disseminazione nel mondo.

✓L'attuale **Sistema SI** è stato approvato per la prima volta dalla 11ma Conferenza Generale CGPM, nel 1960, e successivamente aggiornato e integrato.

https://www.inrim.it/sites/default/files/mediaroot/unita_di_misura/si_revisione.pdf

The SI, 1960-today : what does *not* change

Base and derived units

Base units

Symbol	Unit name
s	second
m	metre
kg	kilogram
A	ampere
K	kelvin
mol	mole
cd	candela

Derived units

$$\mathrm{s}^{\alpha}\,\mathrm{m}^{\beta}\,\mathrm{kg}^{\gamma}\,\mathrm{A}^{\delta}\,\mathrm{K}^{\epsilon}\,\mathrm{mol}^{\zeta}\,\mathrm{cd}^{\eta},$$

where α, β, γ, δ, ϵ, ζ and η are (usually) integers.

SI units for electromagnetic quantities

Derived units with special names

Derived quantity	name	symbol	expression in terms of base units
frequency	hertz	Hz	s^{-1}
energy	joule	J	$m^2\,kg\,s^{-2}$
power	watt	W	$m^2\,kg\;s^{-3}$
electric charge	coulomb	C	$s\;A$
electric potential difference	volt	V	$m^2\;kg\;s^{-3}\;A^{-1}$
electric capacitance	farad	F	$m^{-2}\;kg^{-1}\;s^{-4}\;A^2$
electric resistance	ohm	Ω	$m^2\;kg\;s^{-3}\;A^{-2}$
electric conductance	siemens	S	$m^{-2}\;kg^{-1}\;s^3\;A^2$
magnetic flux	weber	Wb	$m^2\;kg\;s^{-2}\;A^{-1}$
magnetic flux density	tesla	T	$kg\;s^{-2}\;A^{-1}$
inductance	henry	H	$m^2\;kg\;s^{-2}\;A^{-2}$

SI, 1960-2019

The seven base units

m The metre is the length of the path travelled by light in vacuum during a time interval of 1/299792458 of a second.

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

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 caesium-133 atom.

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 m apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per metre of length.

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

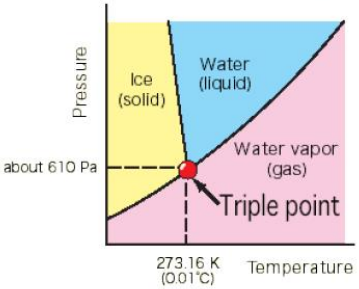
mol The mole is the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kg of carbon 12.

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.

SI, 1960-2019: Definition of units

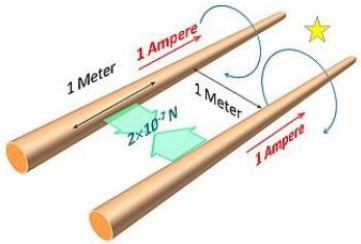
an artefact:

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



a natural property

The kelvin is the fraction $1/273.16$ of the thermodynamic temperature of the triple point of water.



an idealized experiment

The ampere is that constant current which, if maintained in two straight parallel conductors of infinite length [...] would produce a force equal to 2×10^{-7} newton per metre of length

SI, 1960-2019: Realization of the units

Realization (VIM 5.1)

The realization of the definition of a unit can be provided by a measuring system, a material measure, or a reference material.

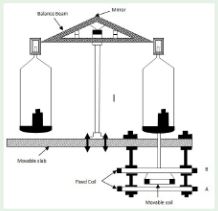
SI 1960-2019:

an artefact:

The international prototype of the kilogram is the realization of the kilogram.

a device

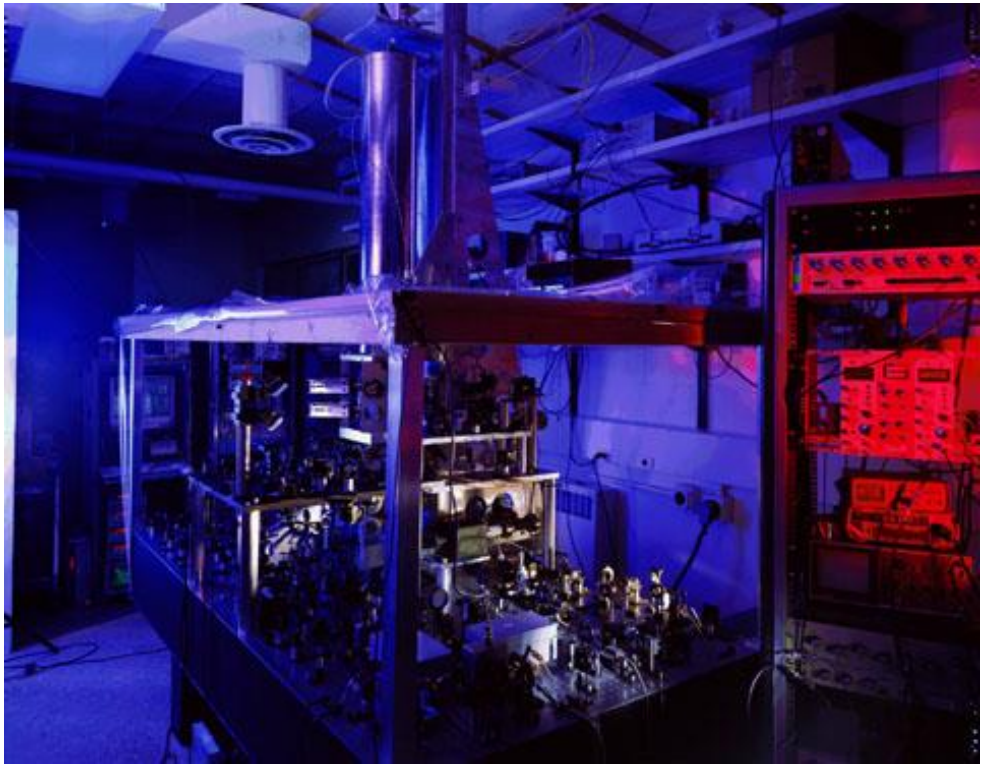
A triple point of water cell is a realization of the kelvin.



an experiment

The current balance is a realization of the ampere.

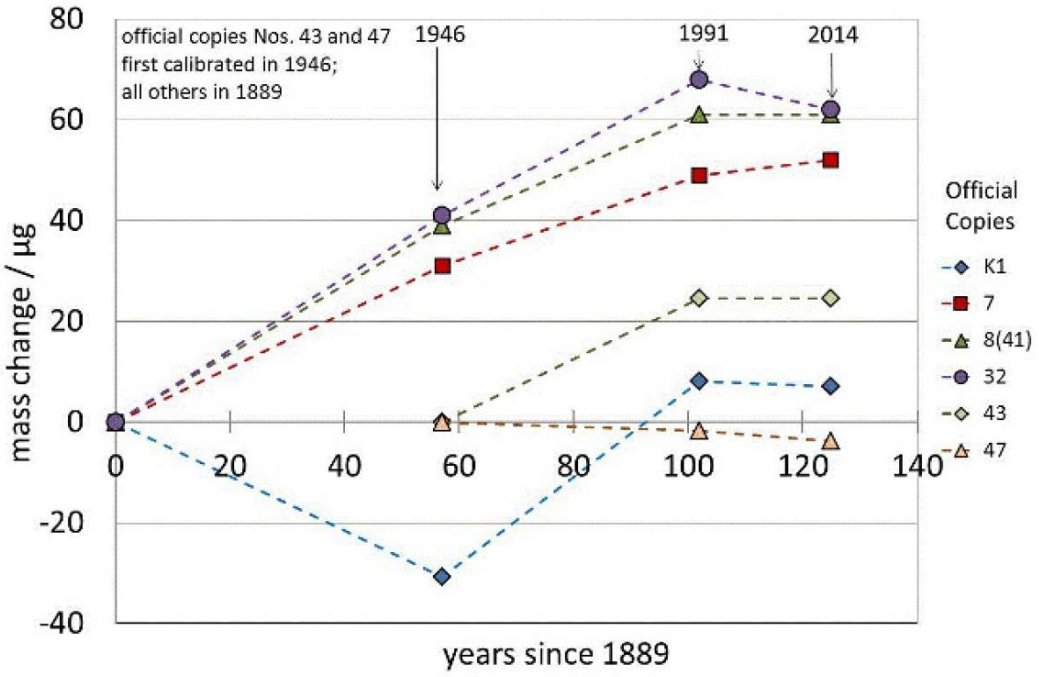
Campione primario per le misure di tempo (es. USA)



Cesium Fountain Atomic Clock NIST-F1. In 2005 the relative uncertainty has been reduced to about $\mathbf{5x10^{-16}}$*, which means it would neither gain nor lose a second in more than 60 million years!*

Massa campione al BIPM

Problem: The drift of the International Prototype



The International Prototype Kilogram compared with its *témoins*
IPK might have lost 35 µg over 130 years

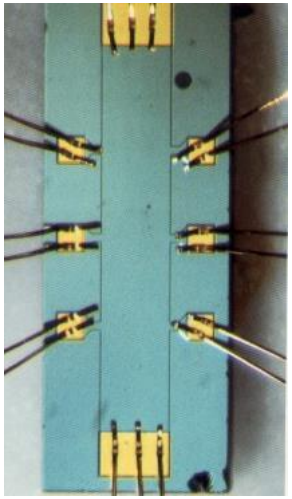
Quantum electrical metrology experiments

Macroscopic quantum effect that display an electrical quantity related to fundamental constants

- quantized resistance: the quantum Hall effect
- quantized flux counting: the Josephson effect
- quantized charge counting: single-electron counting devices

BIPM
Sistema completo
per il riferimento
di tensione
con giunzioni
a effetto Josephson

BIPM
Campione di resistenza
con effetto Hall quantistico

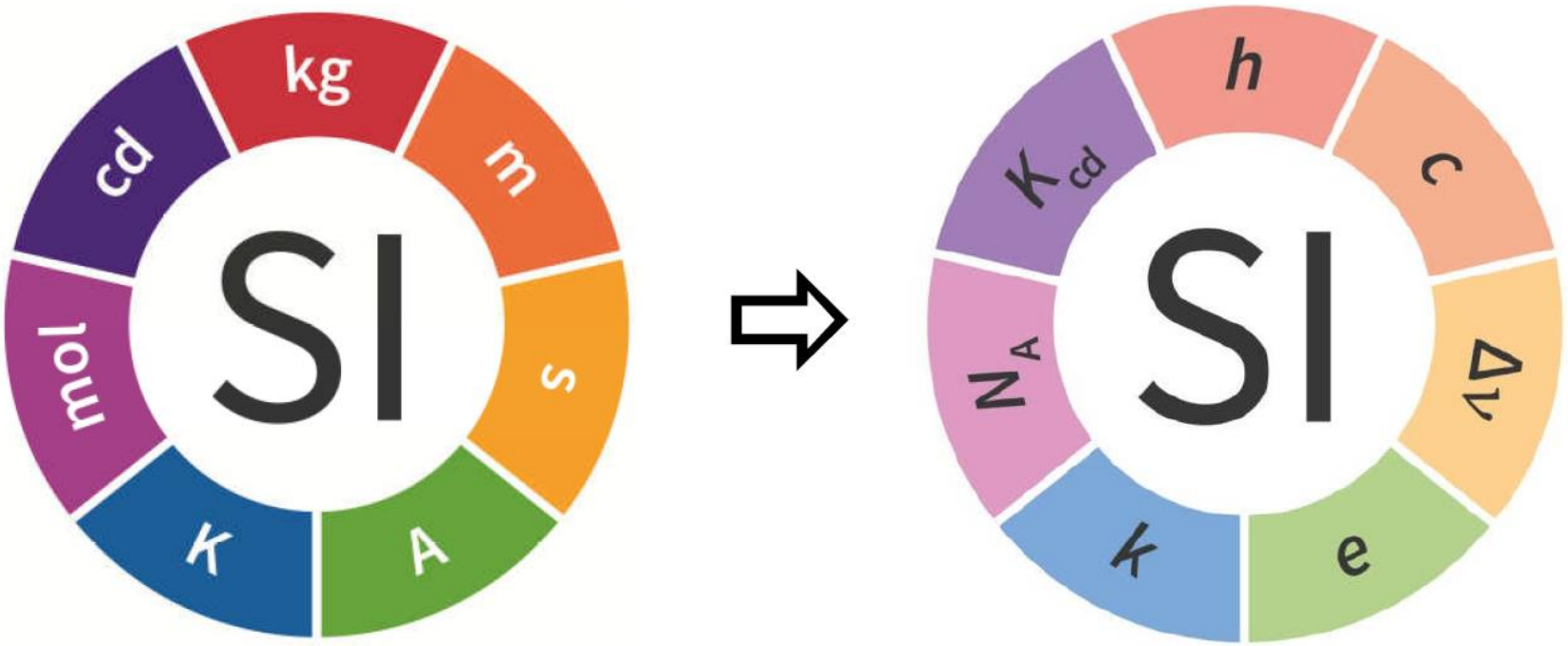


The revision of the SI, 2019-

26th General Conference of Weights and Measures

Implementation day: May 20, 2019, the World Metrology Day

The revision of the SI, 2019-



The revised SI, 2019-

The seven base units

The SI is the system of units in which:

- s The unperturbed ground state hyperfine transition frequency of the caesium 133 atom $\Delta\nu_{Cs}$ is 9 192 631 770 Hz;
- m the speed of light in vacuum c is 299 792 458 m/s;
- kg the Planck constant h is $6.626\,070\,15 \times 10^{-34}$ J s;
- A the elementary charge e is $1.602\,176\,634 \times 10^{-19}$ C;
- K the Boltzmann constant k is $1.380\,649 \times 10^{-23}$ J/K;
- mol the Avogadro constant N_A is $6.022\,140\,76 \times 10^{23}\,\mathrm{mol}^{-1}$;
- cd the luminous efficacy of monochromatic radiation of frequency 540×10^{12} Hz, K_{cd}, is 683 lm/W,

where the hertz, joule, coulomb, lumen, and watt, with unit symbols Hz, J, C, lm, W, respectively, are related to the units second, metre, kilogram, ampere, kelvin, mole, and candela, with unit symbols s, m, kg, A, K, mol, cd, respectively, according to $\mathrm{Hz} = \mathrm{s}^{-1}$, $\mathrm{J} = \mathrm{m}^2\mathrm{kgs}^{-2}$, $\mathrm{C} = \mathrm{A\,s}$, $\mathrm{lm} = \mathrm{cd\,sr}$, $\mathrm{W} = \mathrm{m}^2\mathrm{kg\,s}^{-3}$.

The SI, 2019-: the base units kilogram and ampere

The kilogram:

> *The kilogram, symbol kg, is the SI unit of mass. It is defined by taking the fixed numerical value of the Planck constant h to be $6.626\,070\,15 \times 10^{-34}$ when expressed in the unit J s, which is equal to $\mathrm{kg\,m^2\,s^{-1}}$, where the metre and the second are defined in terms of c and $\Delta\nu_{\mathrm{Cs}}$.*

The ampere:

> *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 $1.602\,176\,634 \times 10^{-19}$ when expressed in the unit C, which is equal to A s, where the second is defined in terms of $\Delta\nu_{\mathrm{Cs}}$.*

The SI, 2019-: the base units kilogram and ampere

The kelvin:

> *The kelvin, symbol K, is the SI unit of thermodynamic temperature. It is defined by taking the fixed numerical value of the Boltzmann constant k to be $1.380\,649 \times 10^{-23}$ when expressed in the unit JK^{-1}, which is equal to $kgm^2\ s^{-2}\ K^{-1}$, where the kilogram, metre and second are defined in terms of h, c and $\Delta\nu_{Cs}$.*

The mole:

> *The mole The mole, symbol mol, is the SI unit of amount of substance. One mole contains $6.022\,140\,76 \times 10^{23}$ 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.*

The new SI, 2019-

Unit definitions do not suggest preferred realisations;

Any physical experiment that satisfies the definition is a realization of the unit

Units can be realized at any level (multiple or submultiple)

Any laboratory can realise the SI units at the uncertainty level of interest

The SI, 2019- : a new status of quantum metrology

e has a fixed value **exact**;

$\Rightarrow$ any electron-counting experiment is a realization of the ampere;

$R_K = \dfrac{h}{e^2}$ is **exact**;

$\Rightarrow$ the quantum Hall effect is a realization of the ohm;

$K_J = \dfrac{2e}{h}$ is **exact**;

$\Rightarrow$ the Josephson effect is a realization of the volt;

$\Rightarrow$ The combined Josephson and quantum Hall effects, through Ohm's law, is a realization of the ampere.

Multipli e sottomultipli

fattore di moltiplicazione			prefisso	
			nome	simbolo
1 000 000 000 000 000 000 000 000	=	10^{24}	yotta	Y
1 000 000 000 000 000 000 000	=	10^{21}	zetta	Z
1 000 000 000 000 000 000	=	10^{18}	exa	E
1 000 000 000 000 000	=	10^{15}	peta	P
1 000 000 000 000	=	10^{12}	tera	T
1 000 000 000	=	10^{9}	giga	G
1 000 000	=	10^{6}	mega	M
1 000	=	10^{3}	kilo	k
100	=	10^{2}	etto	h
10	=	10^{1}	deca	da
0,1	=	10^{-1}	deci	d
0,01	=	10^{-2}	centi	c
0,001	=	10^{-3}	milli	m
0,000 001	=	10^{-6}	micro	μ
0,000 000 001	=	10^{-9}	nano	n
0,000 000 000 001	=	10^{-12}	pico	p
0,000 000 000 000 001	=	10^{-15}	femto	f
0,000 000 000 000 000 001	=	10^{-18}	atto	a
0,000 000 000 000 000 000 001	=	10^{-21}	zepto	z
0,000 000 000 000 000 000 000 001	=	10^{-24}	yocto	y

Unità non SI

Unità	Equivalenza	
pollice	2,54	cm
piede	30,48	cm
yarda	91,44	cm
miglio nautico	1,852	km
gallone (US)	4,5	l
gallone (UK)	3,78	l
kilogrammo forza	9,81	N
kcaloria	4.183	J
British Thermal Unit	1,055	kJ
1 kcal/h	860^{-1}	kW
grado	0,0174	rad