Appendix 1. Decisions of the CGPM and the CIPM

This appendix lists those decisions of the CGPM and the CIPM that bear directly upon definitions of the units of the SI, prefixes defined for use as part of the SI, and conventions for the writing of unit symbols and numbers. It is not a complete list of CGPM and CIPM decisions. For a complete list, reference must be made to successive volumes of the *Comptes Rendus des Séances de la Conférence Générale des Poids et Mesures* (CR) and *Procès-Verbaux des Séances du Comité International des Poids et Mesures* (PV) or, for recent decisions, to *Metrologia*.

Since the SI is not a static convention, but evolves following developments in the science of measurement, some decisions have been abrogated or modified; others have been clarified by additions. Decisions that have been subject to such changes are identified by an asterisk (*) and are linked by a note to the modifying decision.

The original text of each decision (or its translation) is shown in a different font (sans serif) of normal weight to distinguish it from the main text. The asterisks and notes were added by the BIPM to make the text more understandable. They do not form part of the original text.

The decisions of the CGPM and CIPM are listed in this appendix in strict chronological order, from 1889 to 2018, in order to preserve the continuity with which they were taken. However in order to make it easy to locate decisions related to particular topics a table of contents is included below, ordered by subject, with page references to the particular meetings at which decisions relating to each subject were taken.

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1st CGPM, 1889

■ Sanction of the international prototypes of the metre and the kilogram (CR, 34 - 38)*

* The definition of the metre was abrogated in 1960 by the 11th CGPM (Resolution 6, see p. 164).

The Conférence Générale des Poids et Mesures,

considering

- the "Compte rendu of the President of the Comité International des Poids et Mesures (CIPM)" and the "Report of the CIPM", which show that, by the collaboration of the French section of the International Metre Commission and of the CIPM, the fundamental measurements of the international and national prototypes of the metre and of the kilogram have been made with all the accuracy and reliability which the present state of science permits;
- that the international and national prototypes of the metre and the kilogram are made of an alloy of platinum with 10 per cent iridium, to within 0.0001;
- the equality in length of the international Metre and the equality in mass of the international Kilogram with the length of the Metre and the mass of the Kilogram kept in the Archives of France;
- that the differences between the national Metres and the international Metre lie within 0.01 millimetre and that these differences are based on a hydrogen thermometer scale which can always be reproduced thanks to the stability of hydrogen, provided identical conditions are secured;
- that the differences between the national Kilograms and the international Kilogram lie within 1 milligram;
- that the international Metre and Kilogram and the national Metres and Kilograms fulfil the requirements of the Metre Convention,

sanctions

A. As regards international prototypes:

1. The Prototype of the metre chosen by the CIPM. This prototype, at the temperature of melting ice, shall henceforth represent the metric unit of length.
2. The Prototype of the kilogram adopted by the CIPM. This prototype shall henceforth be considered as the unit of mass.
3. The hydrogen thermometer centigrade scale in terms of which the equations of the prototype Metres have been established.

B. As regards national prototypes:

…

3rd CGPM, 1901

■ Declaration concerning the definition of the litre (CR, 38-39)*

* This definition was abrogated in 1964 by the 12th CGPM (Resolution 6, see p. 167).

…

The Conference declares

1. The unit of volume, for high accuracy determinations, is the volume occupied by a mass of 1 kilogram of pure water, at its maximum density and at standard atmospheric pressure: this volume is called "litre".
2. …

■ Declaration on the unit of mass and on the definition of weight; conventional value of g_n (CR, 70)

Taking into account the decision of the Comité International des Poids et Mesures of 15 October 1887, according to which the kilogram has been defined as unit of mass;

Taking into account the decision contained in the sanction of the prototypes of the Metric System, unanimously accepted by the Conférence Générale des Poids et Mesures on 26 September 1889;

Considering the necessity to put an end to the ambiguity which in current practice still exists on the meaning of the word *weight*, used sometimes for *mass*, sometimes for *mechanical force*;

The Conference declares

1. The kilogram is the unit of mass; it is equal to the mass of the international prototype of the kilogram;*
2. The word "weight" denotes a quantity of the same nature as a "force": the weight of a body is the product of its mass and the acceleration due to gravity; in particular, the standard weight of a body is the product of its mass and the standard acceleration due to gravity;
3. The value adopted in the International Service of Weights and Measures for the standard acceleration due to gravity is 980.665 cm/s^2, value already stated in the laws of some countries.**

* This definition was abrogated in 2018 by the 26th CGPM (Resolution 1, see p. 197).

**This value of g_n was the conventional reference for calculating the now obsolete unit kilogram force.

7th CGPM, 1927

■ Definition of the metre by the international Prototype (CR, 49)*

The unit of length is the metre, defined by the distance, at 0°, between the axes of the two central lines marked on the bar of platinum-iridium kept at the Bureau International des Poids et Mesures and declared Prototype of the metre by the 1st Conférence Générale des Poids et Mesures, this bar being subject to standard atmospheric pressure and supported on two cylinders of at least one centimetre diameter, symmetrically placed in the same horizontal plane at a distance of 571 mm from each other.

* This definition was abrogated in 1960 by the 11th CGPM (Resolution 6, see p. 164).

CIPM, 1946

■ Definitions of photometric units (PV, **20**, 119-122)*

Resolution

…

4. The photometric units may be defined as follows:

New candle (unit of luminous intensity). — The value of the new candle is such that the brightness of the full radiator at the temperature of solidification of platinum is 60 new candles per square centimetre.

New lumen (unit of luminous flux). — The new lumen is the luminous flux emitted in unit solid angle (steradian) by a uniform point source having a luminous intensity of 1 new candle.

5. …

* The two definitions contained in this Resolution were ratified in 1948 by the 9th CGPM, which also approved the name candela given to the "new candle" (CR, 54). For the lumen the qualifier "new" was later abandoned.

This definition was modified in 1967 by the 13th CGPM (Resolution 5, see p. 169-170).

■ **Definitions of electric units** (PV, **20**, 132-133)

Resolution 2

...

4. (A) Definitions of the mechanical units which enter the definitions of electric units:

Unit of force. — The unit of force [in the MKS (metre, kilogram, second) system] is the force which gives to a mass of 1 kilogram an acceleration of 1 metre per second, per second.

Joule (unit of energy or work). — The joule is the work done when the point of application of 1 MKS unit of force [newton] moves a distance of 1 metre in the direction of the force.

Watt (unit of power). — The watt is the power which in one second gives rise to energy of 1 joule.

(B) Definitions of electric units. The Comité International des Poids et Mesures (CIPM) accepts the following propositions which define the theoretical value of the electric units:

Ampere (unit of electric current). — 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} MKS unit of force [newton] per metre of length.*

Volt (unit of potential difference and of electromotive force). — The volt is the potential difference between two points of a conducting wire carrying a constant current of 1 ampere, when the power dissipated between these points is equal to 1 watt.

Ohm (unit of electric resistance). — The ohm is the electric resistance between two points of a conductor when a constant potential difference of 1 volt, applied to these points, produces in the conductor a current of 1 ampere, the conductor not being the seat of any electromotive force.

Coulomb (unit of quantity of electricity). — The coulomb is the quantity of electricity carried in 1 second by a current of 1 ampere.

Farad (unit of capacitance). — The farad is the capacitance of a capacitor between the plates of which there appears a potential difference of 1 volt when it is charged by a quantity of electricity of 1 coulomb.

Henry (unit of electric inductance). — The henry is the inductance of a closed circuit in which an electromotive force of 1 volt is produced when the electric current in the circuit varies uniformly at the rate of 1 ampere per second.

Weber (unit of magnetic flux). — The weber is the magnetic flux which, linking a circuit of one turn, would produce in it an electromotive force of 1 volt if it were reduced to zero at a uniform rate in 1 second.

The definitions contained in this Resolution were ratified in 1948 by the 9th CGPM (CR, 49), which also adopted the name newton (Resolution 7, see p. 162) for the MKS unit of force.

In 1954, the 10th CGPM (Resolution 6, see p. 163) established a practical system of units of measurement for international use. The ampere was designated as a base unit of this system.

* This definition of the ampere was abrogated in 2018 by the 26th CGPM (Resolution 1, see p. 197).

9th CGPM, 1948

■ **Triple point of water; thermodynamic scale with a single fixed point; unit of quantity of heat (joule)** (CR, 55 and 63)

Resolution 3

1. With present-day techniques, the triple point of water is capable of providing a thermometric reference point with an accuracy higher than can be obtained from the melting point of ice.

   In consequence the Comité Consultatif de Thermométrie et Calorimétrie (CCTC) considers that the zero of the centesimal thermodynamic scale must be defined as the temperature 0.0100 degree below that of the triple point of water.

2. The CCTC accepts the principle of an absolute thermodynamic scale with a single fundamental fixed point, at present provided by the triple point of pure water, the absolute temperature of which will be fixed at a later date.

   The introduction of this new scale does not affect in any way the use of the International Scale, which remains the recommended practical scale.

3. The unit of quantity of heat is the joule.

The kelvin was redefined by the 26th CGPM in 2018 (Resolution 1, see p. 197).

Note: It is requested that the results of calorimetric experiments be as far as possible expressed in joules. If the experiments are made by comparison with the rise of temperature of water (and that, for some reason, it is not possible to avoid using the calorie), the information necessary for conversion to joules must be provided. The CIPM, advised by the CCTC, should prepare a table giving, in joules per degree, the most accurate values that can be obtained from experiments on the specific heat of water.

A table, prepared in response to this request, was approved and published by the CIPM in 1950 (PV, **22**, 92).

■ **Adoption of “degree Celsius”** [**CIPM, 1948** (PV**, 21,** 88) **and 9th CGPM**, **1948** (CR, 64)]

From three names (“degree centigrade”, “centesimal degree”, “degree Celsius”) proposed to denote the degree of temperature, the CIPM has chosen “degree Celsius” (PV, **21**, 88).

This name is also adopted by the 9th CGPM (CR, 64).

■ **Proposal for establishing a practical system of units of measurement** (CR, 64)

Resolution 6

The Conférence Générale des Poids et Mesures (CGPM),

considering

- that the Comité International des Poids et Mesures (CIPM) has been requested by the International Union of Physics to adopt for international use a practical Système International d’Unités; that the International Union of Physics recommends the MKS system and one electric unit of the absolute practical system, but does not recommend that the CGS system be abandoned by physicists;
- that the CGPM has itself received from the French Government a similar request, accompanied by a draft to be used as basis of discussion for the establishment of a complete specification of units of measurement;

instructs the CIPM:

- to seek by an energetic, active, official enquiry the opinion of scientific, technical and educational circles of all countries (offering them, in fact, the French document as basis);
- to gather and study the answers;
- to make recommendations for a single practical system of units of measurement, suitable for adoption by all countries adhering to the Metre Convention.

■ **Writing and printing of unit symbols and of numbers** (CR, 70)*

Resolution 7

Principles

Roman (upright) type, in general lower-case, is used for symbols of units; if, however, the symbols are derived from proper names, capital roman type is used. These symbols are not followed by a full stop.

In numbers, the comma (French practice) or the dot (British practice) is used only to separate the integral part of numbers from the decimal part. Numbers may be divided in groups of three in order to facilitate reading; neither dots nor commas are ever inserted in the spaces between groups.

Unit	Symbol	Unit	Symbol
• metre	m	ampere	A
• square metre	m^2	volt	V
• cubic metre	m^3	watt	W
• micron	µ	ohm	Ω
• litre	l	coulomb	C
• gram	g	farad	F
• tonne	t	henry	H
second	s	hertz	Hz
erg	erg	poise	P
dyne	dyn	newton	N
degree Celsius	°C	• candela (new candle)	cd
• degree absolute	°K	lux	lx
calorie	cal	lumen	lm
bar	bar	stilb	sb
hour	h		

Notes

1. The symbols whose unit names are preceded by dots are those which had already been adopted by a decision of the CIPM.
2. The symbol for the stere, the unit of volume for firewood, shall be “st” and not “s”, which had been previously assigned to it by the CIPM.
3. To indicate a temperature interval or difference, rather than a temperature, the word “degree” in full, or the abbreviation “deg”, must be used.

* The CGPM abrogated certain decisions on units and terminology, in particular: micron, degree absolute, and the terms “degree”, and “deg”, 13th CGPM, 1967/68 (Resolutions 7 and 3, see pp. 170 and 169, respectively), and the litre; 16th CGPM, 1979 (Resolution 6, see p. 174).

10th CGPM, 1954

■ **Definition of the thermodynamic temperature scale** (CR, 79)*

Resolution 3

The 10th Conférence Générale des Poids et Mesures decides to define the thermodynamic temperature scale by choosing the triple point of water as the fundamental fixed point, and assigning to it the temperature 273.16 degrees Kelvin, exactly.

* The 13th CGPM in 1967 explicitly defined the kelvin (Resolution 4, see p. 169).

* The kelvin was redefined by the 26th CGPM in 2018 (Resolution 1, see p. 197).

■ **Definition of the standard atmosphere** (CR, 79)

Resolution 4

The 10th Conférence Générale des Poids et Mesures (CGPM), having noted that the definition of the standard atmosphere given by the 9th CGPM when defining the International Temperature Scale led some physicists to believe that this definition of the standard atmosphere was valid only for accurate work in thermometry,

declares that it adopts, for general use, the definition:

1 standard atmosphere = 1 013 250 dynes per square centimetre,

i.e., 101 325 newtons per square metre.

■ **Practical system of units** (CR, 80)*

Resolution 6

In accordance with the wish expressed by the 9th Conférence Générale des Poids et Mesures (CGPM) in its Resolution 6 concerning the establishment of a practical system of units of measurement for international use, the 10th CGPM

decides to adopt as base units of the system, the following units:

length	metre
mass	kilogram
time	second
electric current	ampere
thermodynamic temperature	degree Kelvin
luminous intensity	candela

* The unit name "degree kelvin" was changed to "kelvin" in 1967 by the 13th CGPM (Resolution 3, see p. 169).

CIPM, 1956

■ **Definition of the unit of time (second)** (PV, **25**, 77)*

Resolution 1

In virtue of the powers invested in it by Resolution 5 of the 10th Conférence Générale des Poids et Mesures, the Comité International des Poids et Mesures,

considering

1. that the 9th General Assembly of the International Astronomical Union (Dublin, 1955) declared itself in favour of linking the second to the tropical year,
2. that, according to the decisions of the 8th General Assembly of the International Astronomical Union (Rome, 1952), the second of ephemeris time (ET) is the fraction

$$\frac{12\,960\,276\,813}{408\,986\,496} \times 10^{-9} \text{ of the tropical year for 1900 January 0 at 12 h ET,}$$

decides

"The second is the fraction 1/31 556 925.9747 of the tropical year for 1900 January 0 at 12 hours ephemeris time."

* This definition was abrogated in 1967 by the 13th CGPM (Resolution 1, see p. 168).

■ **Système International d'Unités** (PV, **25**, 83)

Resolution 3

The Comité International des Poids et Mesures,

considering

- the task entrusted to it by Resolution 6 of the 9th Conférence Générale des Poids et Mesures (CGPM) concerning the establishment of a practical system of units of measurement suitable for adoption by all countries adhering to the Metre Convention,
- the documents received from twenty-one countries in reply to the enquiry requested by the 9th CGPM,
- Resolution 6 of the 10th CGPM, fixing the base units of the system to be established,

recommends

1. that the name "Système International d'Unités" be given to the system founded on the base units adopted by the 10th CGPM, viz.:

   [This is followed by the list of the six base units with their symbols, reproduced in Resolution 12 of the 11th CGPM (1960)].

2. that the units listed in the table below be used, without excluding others which might be added later:

   [This is followed by the table of units reproduced in paragraph 4 of Resolution 12 of the 11th CGPM (1960)].

11th CGPM, 1960

■ **Definition of the metre** (CR, 85)*

* This definition was abrogated in 1983 by the 17th CGPM (Resolution 1, see p. 175).

Resolution 6

The 11th Conférence Générale des Poids et Mesures (CGPM),

considering

- that the international Prototype does not define the metre with an accuracy adequate for the present needs of metrology,
- that it is moreover desirable to adopt a natural and indestructible standard,

decides

1. The metre is the length equal to 1 650 763.73 wavelengths in vacuum of the radiation corresponding to the transition between the levels $2p_{10}$ and $5d_5$ of the krypton 86 atom.
2. The definition of the metre in force since 1889, based on the international Prototype of platinum-iridium, is abrogated.
3. The international Prototype of the metre sanctioned by the 1st CGPM in 1889 shall be kept at the BIPM under the conditions specified in 1889.

■ **Definition of the unit of time (second)** (CR, 86)*

* This definition was abrogated in 1967 by the 13th CGPM (Resolution 1, see p. 168).

Resolution 9

The 11th Conférence Générale des Poids et Mesures (CGPM),

considering

- the powers given to the Comité International des Poids et Mesures (CIPM) by the 10th CGPM to define the fundamental unit of time,
- the decision taken by the CIPM in 1956,

ratifies the following definition:

"The second is the fraction 1/31 556 925.9747 of the tropical year for 1900 January 0 at 12 hours ephemeris time."

■ **Système International d'Unités** (CR, 87)*

Resolution 12

The 11th Conférence Générale des Poids et Mesures (CGPM),

considering

- Resolution 6 of the 10th CGPM, by which it adopted six base units on which to establish a practical system of measurement for international use:

length	metre	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
thermodynamic temperature	degree Kelvin	°K
luminous intensity	candela	cd

- Resolution 3 adopted by the Comité International des Poids et Mesures (CIPM) in 1956,
- the recommendations adopted by the CIPM in 1958 concerning an abbreviation for the name of the system, and prefixes to form multiples and submultiples of the units,

decides

1. the system founded on the six base units above is called the "Système International d'Unités";
2. the international abbreviation of the name of the system is: SI;
3. names of multiples and submultiples of the units are formed by means of the following prefixes:

Multiplying factor	Prefix	Symbol	Multiplying factor	Prefix	Symbol
1 000 000 000 000 = 10^{12}	tera	T	0.1 = 10^{-1}	deci	d
1 000 000 000 = 10^{9}	giga	G	0.01 = 10^{-2}	centi	c
1 000 000 = 10^{6}	mega	M	0.001 = 10^{-3}	milli	m
1 000 = 10^{3}	kilo	k	0.000 001 = 10^{-6}	micro	μ
100 = 10^{2}	hecto	h	0.000 000 001 = 10^{-9}	nano	n
10 = 10^{1}	deca	da	0.000 000 000 001 = 10^{-12}	pico	p

4. the units listed below are used in the system, without excluding others which might be added later.

Supplementary units

plane angle	radian	rad
solid angle	steradian	sr

* The CGPM later abrogated certain of its decisions and extended the list of prefixes, see notes below.

The name and symbol for the unit of thermodynamic temperature was modified by the 13th CGPM in 1967 (Resolution 3, see p. 169).

A seventh base unit, the mole, was adopted by the 14th CGPM in 1971 (Resolution 3, see p. 172).

Further prefixes were adopted by the 12th CGPM in 1964 (Resolution 8, see p. 168), the 15th CGPM in 1975 (Resolution 10, see p. 173) and the 19th CGPM in 1991 (Resolution 4, see p. 179).

The 20th CGPM in 1995 abrogated the class of supplementary units in the SI (Resolution 8, see p. 179). These are now considered as derived units.

Derived units

area	square metre	m^2	
volume	cubic metre	m^3	
frequency	hertz	Hz	1/s
mass density (density)	kilogram per cubic metre	kg/m^3	
speed, velocity	metre per second	m/s	
angular velocity	radian per second	rad/s	
acceleration	metre per second squared	m/s^2	
angular acceleration	radian per second squared	rad/s^2	
force	newton	N	$kg \cdot m/s^2$
pressure (mechanical stress)	newton per square metre	N/m^2	
kinematic viscosity	square metre per second	m^2/s	
dynamic viscosity	newton-second per square metre	$N \cdot s/m^2$	
work, energy, quantity of heat	joule	J	$N \cdot m$
power	watt	W	J/s
quantity of electricity (side bar)	coulomb	C	$A \cdot s$
tension (voltage), potential difference, electromotive force	volt	V	W/A
electric field strength	volt per metre	V/m	
electric resistance	ohm	Ω	V/A
capacitance	farad	F	$A \cdot s/V$
magnetic flux	weber	Wb	$V \cdot s$
inductance	henry	H	$V \cdot s/A$
magnetic flux density	tesla	T	Wb/m^2
magnetic field strength	ampere per metre	A/m	
magnetomotive force	ampere	A	
luminous flux	lumen	lm	$cd \cdot sr$
luminance	candela per square metre	cd/m^2	
illuminance	lux	lx	lm/m^2

The 13th CGPM in 1967 (Resolution 6, see p. 170) specified other units which should be added to the list. In principle, this list of derived units is without limit.

Modern practice is to use the phrase "amount of heat" rather than "quantity of heat", because the word quantity has a different meaning in metrology.

Modern practice is to use the phrase "amount of electricity" rather than "quantity of electricity" (see note above).

■ **Cubic decimetre and litre** (CR, 88)

Resolution 13

The 11th Conférence Générale des Poids et Mesures (CGPM),

considering

- that the cubic decimetre and the litre are unequal and differ by about 28 parts in 10^6,
- that determinations of physical quantities which involve measurements of volume are being made more and more accurately, thus increasing the risk of confusion between the cubic decimetre and the litre,

requests the Comité International des Poids et Mesures to study the problem and submit its conclusions to the 12th CGPM.

CIPM, 1961

■ **Cubic decimetre and litre** (PV, **29**, 34)

Recommendation

The Comité International des Poids et Mesures recommends that the results of accurate measurements of volume be expressed in units of the International System and not in litres.

CIPM, 1964

■ **Atomic and molecular frequency standards** (PV, **32**, 26)

Declaration

The Comité International des Poids et Mesures,

empowered by Resolution 5 of the 12th Conférence Générale des Poids et Mesures to name atomic or molecular frequency standards for temporary use for time measurements in physics,

declares that the standard to be employed is the transition between the hyperfine levels $F = 4$, $M = 0$ and $F = 3$, $M = 0$ of the ground state $^2S_{1/2}$ of the caesium 133 atom, unperturbed by external fields, and that the frequency of this transition is assigned the value 9 192 631 770 hertz.

12th CGPM, 1964

■ **Atomic standard of frequency** (CR, 93)

Resolution 5

The 12th Conférence Générale des Poids et Mesures (CGPM),

considering

- that the 11th CGPM noted in its Resolution 10 the urgency, in the interests of accurate metrology, of adopting an atomic or molecular standard of time interval,
- that, in spite of the results already obtained with caesium atomic frequency standards, the time has not yet come for the CGPM to adopt a new definition of the second, base unit of the Système International d'Unités, because of the new and considerable improvements likely to be obtained from work now in progress,

considering also that it is not desirable to wait any longer before time measurements in physics are based on atomic or molecular frequency standards,

empowers the Comité International des Poids et Mesures to name the atomic or molecular frequency standards to be employed for the time being,

requests the organizations and laboratories knowledgeable in this field to pursue work connected with a new definition of the second.

■ **Litre** (CR, 93)

Resolution 6

The 12th Conférence Générale des Poids et Mesures (CGPM),

considering Resolution 13 adopted by the 11th CGPM in 1960 and the Recommendation adopted by the Comité International des Poids et Mesures in 1961,

1. **abrogates** the definition of the litre given in 1901 by the 3rd CGPM,
2. **declares** that the word "litre" may be employed as a special name for the cubic decimetre,
3. **recommends** that the name litre should not be employed to give the results of high-accuracy volume measurements.

■ **Curie** (CR, 94)*****

Resolution 7

The 12th Conférence Générale des Poids et Mesures,

considering that the curie has been used for a long time in many countries as unit of activity for radionuclides,

recognizing that in the Système International d'Unités (SI), the unit of this activity is the second to the power of minus one (s^{-1}),

accepts that the curie be still retained, outside SI, as unit of activity, with the value 3.7×10^{10} s^{-1}. The symbol for this unit is Ci.

* The name "becquerel" (Bq) was adopted by the 15th CGPM in 1975 (Resolution 8, see p. 172) for the SI unit of activity: 1 Ci = 3.7×10^{10} Bq.

■ **SI prefixes femto and atto** (CR, 94)*****

Resolution 8

The 12th Conférence Générale des Poids et Mesures (CGPM)

decides to add to the list of prefixes for the formation of names of multiples and submultiples of units, adopted by the 11th CGPM, Resolution 12, paragraph 3, the following two new prefixes:

Multiplying factor	Prefix	Symbol
10^{-15}	femto	f
10^{-18}	atto	a

* New prefixes were added by the 15th CGPM in 1975 (Resolution 10, see p. 173).

CIPM, 1967

■ **Decimal multiples and submultiples of the unit of mass** (PV, **35,** 29 and *Metrologia*, 1968, **4**, 45)

Recommendation 2

The Comité International des Poids et Mesures,

considering that the rule for forming names of decimal multiples and submultiples of the units of paragraph 3 of Resolution 12 of the 11th Conférence Générale des Poids et Mesures (CGPM) (1960) might be interpreted in different ways when applied to the unit of mass,

declares that the rules of Resolution 12 of the 11th CGPM apply to the kilogram in the following manner: the names of decimal multiples and submultiples of the unit of mass are formed by attaching prefixes to the word "gram".

13th CGPM, 1967/68

■ **SI unit of time (second)** (CR, 103 and *Metrologia*, 1968, **4**, 43)

Resolution 1

The 13th Conférence Générale des Poids et Mesures (CGPM),

considering

- that the definition of the second adopted by the Comité International des Poids et Mesures (CIPM) in 1956 (Resolution 1) and ratified by Resolution 9 of the 11th CGPM (1960), later upheld by Resolution 5 of the 12th CGPM (1964), is inadequate for the present needs of metrology,
- that at its meeting of 1964 the CIPM, empowered by Resolution 5 of the 12th CGPM (1964), recommended, in order to fulfil these requirements, a caesium atomic frequency standard for temporary use,
- that this frequency standard has now been sufficiently tested and found sufficiently accurate to provide a definition of the second fulfilling present requirements,
- that the time has now come to replace the definition now in force of the unit of time of the Système International d'Unités by an atomic definition based on that standard,

decides

1. The SI unit of time is the second defined as follows:

   "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";

2. Resolution 1 adopted by the CIPM at its meeting of 1956 and Resolution 9 of the 11th CGPM are now abrogated.

At its 1997 meeting, the CIPM affirmed that this definition refers to a caesium atom at rest at a thermodynamic temperature of 0 K. The wording of the definition of the second was modified by the 26th CGPM in 2018 (Resolution 1, see p. 197).

■ SI unit of thermodynamic temperature (kelvin) (CR, 104 and *Metrologia*, 1968, **4**, 43)*

* At its 1980 meeting, the CIPM approved the report of the 7th meeting of the CCU, which requested that the use of the symbols "°K" and "deg" no longer be permitted.

Resolution 3

The 13th Conférence Générale des Poids et Mesures (CGPM),

considering

- the names "degree Kelvin" and "degree", the symbols "°K" and "deg" and the rules for their use given in Resolution 7 of the 9th CGPM (1948), in Resolution 12 of the 11th CGPM (1960), and the decision taken by the Comité International des Poids et Mesures in 1962 (PV, **30**, 27),
- that the unit of thermodynamic temperature and the unit of temperature interval are one and the same unit, which ought to be denoted by a single name and a single symbol,

decides

1. the unit of thermodynamic temperature is denoted by the name "kelvin" and its symbol is "K";**
2. the same name and the same symbol are used to express a temperature interval;
3. a temperature interval may also be expressed in degrees Celsius;
4. the decisions mentioned in the opening paragraph concerning the name of the unit of thermodynamic temperature, its symbol and the designation of the unit to express an interval or a difference of temperatures are abrogated, but the usages which derive from these decisions remain permissible for the time being.

** See Recommendation 2 (CI-2005) of the CIPM on the isotopic composition of water entering in the definition of the kelvin, p. 184.

■ Definition of the SI unit of thermodynamic temperature (kelvin) (CR, 104 and *Metrologia*, 1968, **4**, 43)*

* See Recommendation 5 (CI-1989) of the CIPM on the International Temperature Scale of 1990, p. 178.

Resolution 4

The 13th Conférence Générale des Poids et Mesures (CGPM),

considering that it is useful to formulate more explicitly the definition of the unit of thermodynamic temperature contained in Resolution 3 of the 10th CGPM (1954),

decides to express this definition as follows:

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

* The kelvin was redefined by the 26th CGPM in 2018 (Resolution 1, see p. 197).

■ SI unit of luminous intensity (candela) (CR, 104 and *Metrologia*, 1968, **4**, 43-44)*

* This definition was abrogated by the 16th CGPM in 1979 (Resolution 3, see p. 173).

Resolution 5

The 13th Conférence Générale des Poids et Mesures (CGPM),

considering

- the definition of the unit of luminous intensity ratified by the 9th CGPM (1948) and contained in the "Resolution concerning the change of photometric units" adopted by the Comité International des Poids et Mesures in 1946 (PV, **20**, 119) in virtue of the powers conferred by the 8th CGPM (1933),
- that this definition fixes satisfactorily the unit of luminous intensity, but that its wording may be open to criticism,

decides to express the definition of the candela as follows:

"The candela is the luminous intensity, in the perpendicular direction, of a surface of 1/600 000 square metre of a black body at the temperature of freezing platinum under a pressure of 101 325 newtons per square metre."

■ SI derived units (CR, 105 and *Metrologia*, 1968, **4**, 44)*

* The unit of activity was given a special name and symbol by the 15th CGPM in 1975 (Resolution 8, see p. 172).

Resolution 6

The 13th Conférence Générale des Poids et Mesures (CGPM),

considering that it is useful to add some derived units to the list of paragraph 4 of Resolution 12 of the 11th CGPM (1960),

decides to add:

wave number	1 per metre	m^{-1}
entropy	joule per kelvin	J/K
specific heat capacity	joule per kilogram kelvin	J/(kg · K)
thermal conductivity	watt per metre kelvin	W/(m · K)
radiant intensity	watt per steradian	W/sr
activity (of a radioactive source)	1 per second	s^{-1}

■ Abrogation of earlier decisions (micron and new candle) (CR, 105 and *Metrologia*, 1968, **4**, 44)

Resolution 7

The 13th Conférence Générale des Poids et Mesures (CGPM),

considering that subsequent decisions of the General Conference concerning the Système International d'Unités are incompatible with parts of Resolution 7 of the 9th CGPM (1948),

decides accordingly to remove from Resolution 7 of the 9th Conference:

1. the unit name "micron", and the symbol "µ" which had been given to that unit but which has now become a prefix;
2. the unit name "new candle".

CIPM, 1969

■ Système International d'Unités, Rules for application of Resolution 12 of the 11th CGPM (1960) (PV, **37**, 30 and *Metrologia*, 1970, **6**, 66)*

* The 20th CGPM in 1995 decided to abrogate the class of supplementary units in the SI (Resolution 8, see p. 179).

Recommendation 1

The Comité International des Poids et Mesures,

considering that Resolution 12 of the 11th Conférence Générale des Poids et Mesures (CGPM) (1960), concerning the Système International d'Unités, has provoked discussions on certain of its aspects,

declares

1. the base units, the supplementary units and the derived units of the Système International d'Unités, which form a coherent set, are denoted by the name "SI units";**
2. the prefixes adopted by the CGPM for the formation of decimal multiples and submultiples of SI units are called "SI prefixes";

and **recommends**

3. the use of SI units and of their decimal multiples and submultiples whose names are formed by means of SI prefixes.

Note: The name "supplementary units", appearing in Resolution 12 of the 11th CGPM (and in the present Recommendation) is given to SI units for which the General Conference declines to state whether they are base units or derived units.

** The CIPM approved in 2001 a proposal of the CCU to clarify the definition of "SI units" and "units of the SI", see p. 180.

CCDS, 1970 (*In* CIPM, 1970)

■ Definition of TAI (PV, **38**, 110-111 and *Metrologia*, 1971, **7**, 43)

Recommendation S 2

International Atomic Time (TAI) is the time reference coordinate established by the Bureau International de l'Heure on the basis of the readings of atomic clocks operating in various establishments in accordance with the definition of the second, the unit of time of the International System of Units.

In 1980, the definition of TAI was completed as follows (declaration of the CCDS, *BIPM Com. Cons. Déf. Seconde*, 1980, **9**, S 15 and *Metrologia*, 1981, **17**, 70):

TAI is a coordinate time scale defined in a geocentric reference frame with the SI second as realized on the rotating geoid as the scale unit.

This definition was further amplified by the International Astronomical Union in 1991, Resolution A4:

"TAI is a realized time scale whose ideal form, neglecting a constant offset of 32.184 s, is Terrestrial Time (TT), itself related to the time coordinate of the geocentric reference frame, Geocentric Coordinate Time (TCG), by a constant rate."

(see Proc. 21st General Assembly of the IAU, *IAU Trans.*, 1991, vol. **XXIB,** Kluwer.)

14th CGPM, 1971

■ Pascal and siemens (CR, 78)

The 14th Conférence Générale des Poids et Mesures adopted the special names "pascal" (symbol Pa), for the SI unit newton per square metre, and "siemens" (symbol S), for the SI unit of electric conductance [reciprocal ohm].

■ International Atomic Time, function of CIPM (CR, 77-78 and *Metrologia*, 1972, **8**, 35)

Resolution 1

The 14th Conférence Générale des Poids et Mesures (CGPM),

considering

- that the second, unit of time of the Système International d'Unités, has since 1967 been defined in terms of a natural atomic frequency, and no longer in terms of the time scales provided by astronomical motions,
- that the need for an International Atomic Time (TAI) scale is a consequence of the atomic definition of the second,
- that several international organizations have ensured and are still successfully ensuring the establishment of the time scales based on astronomical motions, particularly thanks to the permanent services of the Bureau International de l'Heure (BIH),
- that the BIH has started to establish an atomic time scale of recognized quality and proven usefulness,
- that the atomic frequency standards for realizing the second have been considered and must continue to be considered by the Comité International des Poids et Mesures (CIPM) helped by a Consultative Committee, and that the unit interval of the International Atomic Time scale must be the second realized according to its atomic definition,
- that all the competent international scientific organizations and the national laboratories active in this field have expressed the wish that the CIPM and the CGPM should give a definition of International Atomic Time, and should contribute to the establishment of the International Atomic Time scale,
- that the usefulness of International Atomic Time entails close coordination with the time scales based on astronomical motions,

requests the CIPM

1. to give a definition of International Atomic Time,
2. to take the necessary steps, in agreement with the international organizations concerned, to ensure that available scientific competence and existing facilities are used in the best possible way to realize the International Atomic Time scale and to satisfy the requirements of users of International Atomic Time.

The definition of TAI was given by the CCDS in 1970 (now the CCTF), see CCDS report p. 22.

■ **SI unit of amount of substance (mole)** (CR, 78 and *Metrologia*, 1972, **8**, 36)*****

Resolution 3

The 14th Conférence Générale des Poids et Mesures (CGPM),

considering the advice of the International Union of Pure and Applied Physics, of the International Union of Pure and Applied Chemistry, and of the International Organization for Standardization, concerning the need to define a unit of amount of substance,

decides

1. 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; its symbol is "mol".**
2. 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.
3. The mole is a base unit of the Système International d'Unités.

* At its 1980 meeting, the CIPM approved the report of the 7th meeting of the CCU (1980) specifying that, in this definition, it is understood that unbound atoms of carbon 12, at rest and in their ground state, are referred to.

** The mole was redefined by the 26th CGPM in 2018 (Resolution 1, see p. 197).

15th CGPM, 1975

■ **Recommended value for the speed of light** (CR, 103 and *Metrologia*, 1975, **11**, 179-180)

Resolution 2

The 15th Conférence Générale des Poids et Mesures,

considering the excellent agreement among the results of wavelength measurements on the radiations of lasers locked on a molecular absorption line in the visible or infrared region, with an uncertainty estimated at $\pm 4 \times 10^{-9}$ which corresponds to the uncertainty of the realization of the metre,

considering also the concordant measurements of the frequencies of several of these radiations,

recommends the use of the resulting value for the speed of propagation of electromagnetic waves in vacuum c = 299 792 458 metres per second.

The relative uncertainty given here corresponds to three standard deviations in the data considered.

■ **Coordinated Universal Time (UTC)** (CR, 104 and *Metrologia*, 1975, **11**, 180)

Resolution 5

The 15th Conférence Générale des Poids et Mesures,

considering that the system called "Coordinated Universal Time" (UTC) is widely used, that it is broadcast in most radio transmissions of time signals, that this wide diffusion makes available to the users not only frequency standards but also International Atomic Time and an approximation to Universal Time (or, if one prefers, mean solar time),

notes that this Coordinated Universal Time provides the basis of civil time, the use of which is legal in most countries,

judges that this usage can be strongly endorsed.

■ **SI units for ionizing radiation (becquerel and gray)** (CR, 105 and *Metrologia*, 1975, **11**, 180)*****

Resolutions 8 and 9

The 15th Conférence Générale des Poids et Mesures,

by reason of the pressing requirement, expressed by the International Commission on Radiation Units and Measurements (ICRU), to extend the use of the Système International d'Unités to radiological research and applications,

by reason of the need to make as easy as possible the use of the units for nonspecialists,

taking into consideration also the grave risks of errors in therapeutic work,

adopts the following special name for the SI unit of activity:

* At its 1976 meeting, the CIPM approved the report of the 5th meeting of the CCU (1976), specifying that, following the advice of the ICRU, the gray may also be used to express specific energy imparted, kerma and absorbed dose index.

***becquerel**,* symbol Bq, equal to one reciprocal second (Resolution 8),

adopts the following special name for the SI unit of ionizing radiation:

***gray**,* symbol Gy, equal to one joule per kilogram (Resolution 9).

Note: The gray is the SI unit of absorbed dose. In the field of ionizing radiation, the gray may be used with other physical quantities also expressed in joules per kilogram: the Comité Consultatif des Unités has responsibility for studying this matter in collaboration with the competent international organizations.

■ **SI prefixes peta and exa** (CR, 106 and *Metrologia*, 1975, **11**, 180-181)*****

* New prefixes were added by the 19th CGPM in 1991 (Resolution 4, see p. 179).

Resolution 10

The 15th Conférence Générale des Poids et Mesures (CGPM)

decides to add to the list of SI prefixes to be used for multiples, which was adopted by the 11th CGPM, Resolution 12, paragraph 3, the two following prefixes:

Multiplying factor	Prefix	Symbol
10^{15}	peta	P
10^{18}	exa	E

16th CGPM, 1979

■ **SI unit of luminous intensity (candela)** (CR, 100 and *Metrologia*, 1980, **16**, 56)

The wording of the definition of the candela was modified by the 26th CGPM in 2018 (Resolution 1, see p. 197).

Resolution 3

The 16th Conférence Générale des Poids et Mesures (CGPM),

considering

- that despite the notable efforts of some laboratories there remain excessive divergences between the results of realizations of the candela based upon the present black body primary standard,
- that radiometric techniques are developing rapidly, allowing precisions that are already equivalent to those of photometry and that these techniques are already in use in national laboratories to realize the candela without having to construct a black body,
- that the relation between luminous quantities of photometry and radiometric quantities, namely the value of 683 lumens per watt for the spectral luminous efficacy of monochromatic radiation of frequency 540×10^{12} hertz, has been adopted by the Comité International des Poids et Mesures (CIPM) in 1977,
- that this value has been accepted as being sufficiently accurate for the system of luminous photopic quantities, that it implies a change of only about 3 % for the system of luminous scotopic quantities, and that it therefore ensures satisfactory continuity,
- that the time has come to give the candela a definition that will allow an improvement in both the ease of realization and the precision of photometric standards, and that applies to both photopic and scotopic photometric quantities and to quantities yet to be defined in the mesopic field,

Photopic vision is detected by the cones on the retina of the eye, which are sensitive to a high level of luminance ($L >$ ca. 10 cd/m^2) and are used in daytime vision.

Scotopic vision is detected by the rods of the retina, which are sensitive to low level luminance ($L <$ ca. 10^{-3} cd/m^2), used in night vision.

In the domain between these levels of luminance both cones and rods are used, and this is described as mesopic vision.

decides

1. 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.
2. The definition of the candela (at the time called new candle) adopted by the CIPM in 1946 by reason of the powers conferred by the 8th CGPM in 1933, ratified by the 9th CGPM in 1948, then amended by the 13th CGPM in 1967, is abrogated.

■ **Special name for the SI unit of dose equivalent (sievert)** (CR, 100 and *Metrologia*, 1980, **16**, 56)*****

* The CIPM, in 1984, decided to accompany this Resolution with an explanation (Recommendation 1, see p. 176).

Resolution 5

The 16th Conférence Générale des Poids et Mesures,

considering

- the effort made to introduce SI units into the field of ionizing radiations,
- the risk to human beings of an underestimated radiation dose, a risk that could result from a confusion between absorbed dose and dose equivalent,
- that the proliferation of special names represents a danger for the Système International d'Unités and must be avoided in every possible way, but that this rule can be broken when it is a matter of safeguarding human health,

adopts the special name ***sievert,*** symbol Sv, for the SI unit of dose equivalent in the field of radioprotection. The sievert is equal to the joule per kilogram.

■ **Symbols for the litre** (CR, 101 and *Metrologia*, 1980, **16**, 56-57)

Resolution 6

The 16th Conférence Générale des Poids et Mesures (CGPM),

recognizing the general principles adopted for writing the unit symbols in Resolution 7 of the 9th CGPM (1948),

considering that the symbol l for the unit litre was adopted by the Comité International des Poids et Mesures (CIPM) in 1879 and confirmed in the same Resolution of 1948,

considering also that, in order to avoid the risk of confusion between the letter l and the number 1, several countries have adopted the symbol L instead of l for the unit litre,

considering that the name litre, although not included in the Système International d'Unités, must be admitted for general use with the System,

decides*,* as an exception, to adopt the two symbols l and L as symbols to be used for the unit litre,

The CIPM, in 1990, considered that it was still too early to choose a single symbol for the litre.

considering further that in the future only one of these two symbols should be retained,

invites the CIPM to follow the development of the use of these two symbols and to give the 18th CGPM its opinion as to the possibility of suppressing one of them.

CIPM, 1980

■ **SI supplementary units (radian and steradian)** (PV, **48**, 24 and *Metrologia*, 1981, **17**, 72)*****

* The class of SI supplementary units was abrogated by decision of the 20th CGPM in 1995 (Resolution 8, see p. 179).

Recommendation 1

The Comité International des Poids et Mesures (CIPM),

taking into consideration Resolution 3 adopted by ISO/TC 12 in 1978 and Recommendation U 1 (1980) adopted by the Comité Consultatif des Unités at its 7th meeting,

considering

- that the units radian and steradian are usually introduced into expressions for units when there is need for clarification, especially in photometry where the steradian plays an important role in distinguishing between units corresponding to different quantities,
- that in the equations used one generally expresses plane angle as the ratio of two lengths and solid angle as the ratio between an area and the square of a length, and consequently that these quantities are treated as dimensionless quantities,
- that the study of the formalisms in use in the scientific field shows that none exists which is at the same time coherent and convenient and in which the quantities plane angle and solid angle might be considered as base quantities,

considering also

- that the interpretation given by the CIPM in 1969 for the class of supplementary units introduced in Resolution 12 of the 11th Conférence Générale des Poids et Mesures (CGPM) in 1960 allows the freedom of treating the radian and the steradian as SI base units,
- that such a possibility compromises the internal coherence of the SI based on only seven base units,

decides to interpret the class of supplementary units in the International System as a class of dimensionless derived units for which the CGPM allows the freedom of using or not using them in expressions for SI derived units.

17th CGPM, 1983

■ Definition of the metre (CR, 97 and *Metrologia*, 1984, **20**, 25)

The wording of the definition of the metre was modified by the 26th CGPM in 2018 (Resolution 1, see p. 197).

Resolution 1

The 17th Conférence Générale des Poids et Mesures (CGPM),

considering

- that the present definition does not allow a sufficiently precise realization of the metre for all requirements,
- that progress made in the stabilization of lasers allows radiations to be obtained that are more reproducible and easier to use than the standard radiation emitted by a krypton 86 lamp,
- that progress made in the measurement of the frequency and wavelength of these radiations has resulted in concordant determinations of the speed of light whose accuracy is limited principally by the realization of the present definition of the metre,
- that wavelengths determined from frequency measurements and a given value for the speed of light have a reproducibility superior to that which can be obtained by comparison with the wavelength of the standard radiation of krypton 86,
- that there is an advantage, notably for astronomy and geodesy, in maintaining unchanged the value of the speed of light recommended in 1975 by the 15th CGPM in its Resolution 2 (c = 299 792 458 m/s),
- that a new definition of the metre has been envisaged in various forms all of which have the effect of giving the speed of light an exact value, equal to the recommended value, and that this introduces no appreciable discontinuity into the unit of length, taking into account the relative uncertainty of $\pm 4 \times 10^{-9}$ of the best realizations of the present definition of the metre,
- that these various forms, making reference either to the path travelled by light in a specified time interval or to the wavelength of a radiation of measured or specified frequency, have been the object of consultations and deep discussions, have been recognized as being equivalent and that a consensus has emerged in favour of the first form,
- that the Comité Consultatif pour la Définition du Mètre (CCDM) is now in a position to give instructions for the practical realization of such a definition, instructions which could include the use of the orange radiation of krypton 86 used as standard up to now, and which may in due course be extended or revised,

The relative uncertainty given here corresponds to three standard deviations in the data considered.

decides

1. 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,
2. The definition of the metre in force since 1960, based upon the transition between the levels $2p_{10}$ and $5d_5$ of the atom of krypton 86, is abrogated.

■ **On the realization of the definition of the metre** (CR, 98 and *Metrologia*, 1984, **20**, 25-26)

See Recommendation 1 (CI-2002) of the CIPM on the revision of the practical realization of the definition of the metre, p. 181.

Resolution 2

The 17th Conférence Générale des Poids et Mesures,

invites the Comité International des Poids et Mesures

- to draw up instructions for the practical realization of the new definition of the metre,
- to choose radiations which can be recommended as standards of wavelength for the interferometric measurement of length and to draw up instructions for their use,
- to pursue studies undertaken to improve these standards.

CIPM, 1984

■ **Concerning the sievert** (PV, **52**, 31 and *Metrologia*, 1985, **21**, 90)*****

* The CIPM, in 2002, decided to change the explanation of the quantity dose equivalent in the SI Brochure (Recommendation 2, see p. 182).

Recommendation 1

The Comité International des Poids et Mesures,

considering the confusion which continues to exist on the subject of Resolution 5, approved by the 16th Conférence Générale des Poids et Mesures (1979),

decides to introduce the following explanation in the brochure “Le Système International d'Unités (SI)”:

The quantity dose equivalent H is the product of the absorbed dose D of ionizing radiation and the dimensionless factors Q (quality factor) and N (product of any other multiplying factors) stipulated by the International Commission on Radiological Protection:

$$H = Q \cdot N \cdot D.$$

Thus, for a given radiation, the numerical value of H in joules per kilogram may differ from that of D in joules per kilogram depending upon the values of Q and N. In order to avoid any risk of confusion between the absorbed dose D and the dose equivalent H, the special names for the respective units should be used, that is, the name gray should be used instead of joules per kilogram for the unit of absorbed dose D and the name sievert instead of joules per kilogram for the unit of dose equivalent H.

18th CGPM, 1987

■ **Forthcoming adjustment to the representations of the volt and of the ohm** (CR, 100 and *Metrologia*, 1988, **25**, 115)

Resolution 6

The 18th Conférence Générale des Poids et Mesures,

considering

- that worldwide uniformity and long-term stability of national representations of the electrical units are of major importance for science, commerce and industry from both the technical and economic points of view,
- that many national laboratories use the Josephson effect and are beginning to use the quantum Hall effect to maintain, respectively, representations of the volt and of the ohm, as these offer the best guarantees of long-term stability,
- that because of the importance of coherence among the units of measurement of the various physical quantities the values adopted for these representations must be as closely as possible in agreement with the SI,
- that the results of recent and current experiment will permit the establishment of an acceptable value, sufficiently compatible with the SI, for the coefficient which relates each of these effects to the corresponding electrical unit,

invites the laboratories whose work can contribute to the establishment of the quotient voltage/frequency in the case of the Josephson effect and of the quotient voltage/current for the quantum Hall effect to vigorously pursue these efforts and to communicate their results without delay to the Comité International des Poids et Mesures, and

instructs the Comité International des Poids et Mesures to recommend, as soon as it considers it possible, a value for each of these quotients together with a date for them to be put into practice simultaneously in all countries; these values should be announced at least one year in advance and would be adopted on 1 January 1990.

CIPM, 1988

■ Representation of the volt by means of the Josephson effect (PV, **56**, 44 and *Metrologia*, 1989, **26**, 69)*

* The 26th CGPM in 2018 (Resolution 1, see p. 197) abrogated the adoption of a conventional value for K_J.

Recommendation 1

The Comité International des Poids et Mesures,

acting in accordance with instructions given in Resolution 6 of the 18th Conférence Générale des Poids et Mesures concerning the forthcoming adjustment of the representations of the volt and the ohm,

considering

- that a detailed study of the results of the most recent determinations leads to a value of 483 597.9 GHz/V for the Josephson constant, K_J, that is to say, for the quotient of frequency divided by the potential difference corresponding to the $n = 1$ step in the Josephson effect,
- that the Josephson effect, together with this value of K_J, can be used to establish a reference standard of electromotive force having a one-standard-deviation uncertainty with respect to the volt estimated to be 4 parts in 10^7, and a reproducibility which is significantly better,

recommends

- that 483 597.9 GHz/V exactly be adopted as a conventional value, denoted by K_{J-90} for the Josephson constant, K_J,
- that this new value be used from 1 January 1990, and not before, to replace the values currently in use,
- that this new value be used from this same date by all laboratories which base their measurements of electromotive force on the Josephson effect, and
- that from this same date all other laboratories adjust the value of their laboratory reference standards to agree with the new adopted value,

is of the opinion that no change in this recommended value of the Josephson constant will be necessary in the foreseeable future, and

draws the attention of laboratories to the fact that the new value is greater by 3.9 GHz/V, or about 8 parts in 10^6, than the value given in 1972 by the Comité Consultatif d'Électricité in its Declaration E-72.

■ Representation of the ohm by means of the quantum Hall effect (PV, **56**, 45 and *Metrologia*, 1989, **26**, 70)*

At its 89th meeting in 2000, the CIPM approved the declaration of the 22nd meeting of the CCEM on the use of the value of the von Klitzing constant.

*The 26th CGPM in 2018 (Resolution 1, see p. 197) abrogated the adoption of a conventional value for R_K.

Recommendation 2

The Comité International des Poids et Mesures,

acting in accordance with instructions given in Resolution 6 of the 18th Conférence Générale des Poids et Mesures concerning the forthcoming adjustment of the representations of the volt and the ohm,

considering

- that most existing laboratory reference standards of resistance change significantly with time,
- that a laboratory reference standard of resistance based on the quantum Hall effect would be stable and reproducible,
- that a detailed study of the results of the most recent determinations leads to a value of 25 812.807 Ω for the von Klitzing constant, R_K, that is to say, for the quotient of the Hall potential difference divided by current corresponding to the plateau i = 1 in the quantum Hall effect,
- that the quantum Hall effect, together with this value of R_K, can be used to establish a reference standard of resistance having a one-standard-deviation uncertainty with respect to the ohm estimated to be 2 parts in 10^7, and a reproducibility which is significantly better,

recommends

- that 25 812.807 Ω exactly be adopted as a conventional value, denoted by R_{K-90}, for the von Klitzing constant, R_K,
- that this value be used from 1 January 1990, and not before, by all laboratories which base their measurements of resistance on the quantum Hall effect,
- that from this same date all other laboratories adjust the value of their laboratory reference standards to agree with R_{K-90},
- that in the use of the quantum Hall effect to establish a laboratory reference standard of resistance, laboratories follow the most recent edition of the technical guidelines for reliable measurements of the quantized Hall resistance drawn up by the Comité Consultatif d'Électricité and published by the Bureau International des Poids et Mesures, and

is of the opinion that no change in this recommended value of the von Klitzing constant will be necessary in the foreseeable future.

CIPM, 1989

■ **The International Temperature Scale of 1990** (PV, **57**, 115 and *Metrologia*, 1990, **27**, 13)

The kelvin was redefined by the 26th CGPM in 2018 (Resolution 1, see p. 197).

Recommendation 5

The Comité International des Poids et Mesures (CIPM) acting in accordance with Resolution 7 of the 18th Conférence Générale des Poids et Mesures (1987) has adopted the International Temperature Scale of 1990 (ITS-90) to supersede the International Practical Temperature Scale of 1968 (IPTS-68).

The CIPM **notes** that, by comparison with the IPTS-68, the ITS-90

- extends to lower temperatures, down to 0.65 K, and hence also supersedes the EPT-76,
- is in substantially better agreement with corresponding thermodynamic temperatures,
- has much improved continuity, precision and reproducibility throughout its range and
- has subranges and alternative definitions in certain ranges which greatly facilitate its use.

The CIPM also **notes** that, to accompany the text of the ITS-90 there will be two further documents, the *Supplementary Information for the ITS-90* and *Techniques for Approximating the ITS-90*. These documents will be published by the BIPM and periodically updated.

The CIPM **recommends**

- that on 1 January 1990 the ITS-90 come into force and
- that from this same date the IPTS-68 and the EPT-76 be abrogated.

19th CGPM, 1991

■ SI prefixes zetta, zepto, yotta and yocto (CR, 185 and *Metrologia*, 1992, **29**, 3)

The names zepto and zetta are derived from septo suggesting the number seven (the seventh power of 10^3) and the letter "z" is substituted for the letter "s" to avoid the duplicate use of the letter "s" as a symbol. The names yocto and yotta are derived from octo, suggesting the number eight (the eighth power of 10^3); the letter "y" is added to avoid the use of the letter "o" as a symbol because it may be confused with the number zero.

Resolution 4

The 19th Conférence Générale des Poids et Mesures (CGPM)

decides to add to the list of SI prefixes to be used for multiples and submultiples of units, adopted by the 11th CGPM, Resolution 12, paragraph 3, the 12th CGPM, Resolution 8 and the 15th CGPM, Resolution 10, the following prefixes:

Multiplying factor	Prefix	Symbol
10^{21}	zetta	Z
10^{-21}	zepto	z
10^{24}	yotta	Y
10^{-24}	yocto	y

20th CGPM, 1995

■ Elimination of the class of supplementary units in the SI (CR, 223 and *Metrologia*, 1996, **33**, 83)

Resolution 8

The 20th Conférence Générale des Poids et Mesures (CGPM),

considering

- that the 11th Conférence Générale in 1960 in its Resolution 12, establishing the Système International d'Unités, SI, distinguished between three classes of SI units: the base units, the derived units, and the supplementary units, the last of these comprising the radian and the steradian,
- that the status of the supplementary units in relation to the base units and the derived units gave rise to debate,
- that the Comité International des Poids et Mesures, in 1980, having observed that the ambiguous status of the supplementary units compromises the internal coherence of the SI, has in its Recommendation 1 (CI-1980) interpreted the supplementary units, in the SI, as dimensionless derived units,

approving the interpretation given by the Comité International in 1980,

decides

- to interpret the supplementary units in the SI, namely the radian and the steradian, as dimensionless derived units, the names and symbols of which may, but need not, be used in expressions for other SI derived units, as is convenient,
- and, consequently, to eliminate the class of supplementary units as a separate class in the SI.

21st CGPM, 1999

■ The definition of the kilogram (CR, 331 and *Metrologia*, 2000, **37**, 94)

Resolution 7

The 21st Conférence Générale des Poids et Mesures,

considering

- the need to assure the long-term stability of the International System of Units (SI),
- the intrinsic uncertainty in the long-term stability of the artefact defining the unit of mass, one of the base units of the SI,
- the consequent uncertainty in the long-term stability of the other three base units of the SI that depend on the kilogram, namely, the ampere, the mole and the candela,

- the progress already made in a number of different experiments designed to link the unit of mass to fundamental or atomic constants,
- the desirability of having more than one method of making such a link,

recommends that national laboratories continue their efforts to refine experiments that link the unit of mass to fundamental or atomic constants with a view to a future redefinition of the kilogram.

■ Special name for the SI derived unit mole per second, the katal, for the expression of catalytic activity (CR, 334-335 and *Metrologia*, 2000, **37**, 95)

Resolution 12

The 21st Conférence Générale des Poids et Mesures,

considering

- the importance for human health and safety of facilitating the use of SI units in the fields of medicine and biochemistry,
- that a non-SI unit called “unit”, symbol U, equal to 1 $\mu\text{mol} \cdot \text{min}^{-1}$, which is not coherent with the International System of Units (SI), has been in widespread use in medicine and biochemistry since 1964 for expressing catalytic activity,
- that the absence of a special name for the SI coherent derived unit mole per second has led to results of clinical measurements being given in various local units,
- that the use of SI units in medicine and clinical chemistry is strongly recommended by the international unions in these fields,
- that the International Federation of Clinical Chemistry and Laboratory Medicine has asked the Consultative Committee for Units to recommend the special name katal, symbol kat, for the SI unit mole per second,
- that while the proliferation of special names represents a danger for the SI, exceptions are made in matters related to human health and safety (15th General Conference, 1975, Resolutions 8 and 9, 16th General Conference, 1979, Resolution 5),

noting that the name katal, symbol kat, has been used for the SI unit mole per second for over thirty years to express catalytic activity,

decides to adopt the special name katal, symbol kat, for the SI unit mole per second to express catalytic activity, especially in the fields of medicine and biochemistry,

and **recommends** that when the katal is used, the measurand be specified by reference to the measurement procedure; the measurement procedure must identify the indicator reaction.

CIPM, 2001

■ “SI units” and “units of the SI” (PV, **69**, 120)

The CIPM approved in 2001 the following proposal of the CCU regarding “SI units” and “units of the SI”:

“We suggest that “SI units” and “units of the SI” should be regarded as names that include both the base units and the coherent derived units, and also all units obtained by combining these with the recommended multiple and sub-multiple prefixes.

We suggest that the name “coherent SI units” should be used when it is desired to restrict the meaning to only the base units and the coherent derived units.”

CIPM, 2002

■ **Revision of the practical realization of the definition of the metre** (PV, **70**, 194-204 and *Metrologia*, **40**, 103-133)

Recommendation 1

The International Committee for Weights and Measures,

recalling

- that in 1983 the 17th General Conference (CGPM) adopted a new definition of the metre;
- that in the same year the CGPM invited the International Committee (CIPM)
  - to draw up instructions for the practical realization of the metre,
  - to choose radiations which can be recommended as standards of wavelength for the interferometric measurement of length and draw up instructions for their use,
  - to pursue studies undertaken to improve these standards and in due course to extend or revise these instructions;
- that in response to this invitation the CIPM adopted Recommendation 1 (CI-1983) (*mise en pratique* of the definition of the metre) to the effect
  - that the metre should be realized by one of the following methods:

    (a) by means of the length l of the path travelled in vacuum by a plane electromagnetic wave in a time t; this length is obtained from the measured time t, using the relation $l = c_0 \cdot t$ and the value of the speed of light in vacuum c_0 = 299 792 458 m/s,

    (b) by means of the wavelength in vacuum λ of a plane electromagnetic wave of frequency f; this wavelength is obtained from the measured frequency f using the relation $\lambda = c_0 / f$ and the value of the speed of light in vacuum c_0 = 299 792 458 m/s,

    (c) by means of one of the radiations from the list below, whose stated wavelength in vacuum or whose stated frequency can be used with the uncertainty shown, provided that the given specifications and accepted good practice are followed;
  - that in all cases any necessary corrections be applied to take account of actual conditions such as diffraction, gravitation or imperfection in the vacuum;
  - that in the context of general relativity, the metre is considered a unit of proper length. Its definition, therefore, applies only within a spatial extent sufficiently small that the effects of the non-uniformity of the gravitational field can be ignored (note that, at the surface of the Earth, this effect in the vertical direction is about 1 part in 10^{16} per metre). In this case, the effects to be taken into account are those of special relativity only. The local methods for the realization of the metre recommended in (b) and (c) provide the proper metre but not necessarily that given in (a). Method (a) should therefore be restricted to lengths l which are sufficiently short for the effects predicted by general relativity to be negligible with respect to the uncertainties of realization. For advice on the interpretation of measurements in which this is not the case, see the report of the Consultative Committee for Time and Frequency (CCTF) Working Group on the Application of General Relativity to Metrology (Application of general relativity to metrology, *Metrologia*, 1997, **34**, 261-290);
- that the CIPM had already recommended a list of radiations for this purpose;

recalling also that in 1992 and in 1997 the CIPM revised the practical realization of the definition of the metre;

considering

- that science and technology continue to demand improved accuracy in the realization of the metre;
- that since 1997 work in national laboratories, in the BIPM and elsewhere has identified new radiations and methods for their realization which lead to lower uncertainties;

- that there is an increasing move towards optical frequencies for time-related activities, and that there continues to be a general widening of the scope of application of the recommended radiations of the *mise en pratique* to cover not only dimensional metrology and the realization of the metre, but also high-resolution spectroscopy, atomic and molecular physics, fundamental constants and telecommunication;
- that a number of new frequency values with reduced uncertainties for radiations of high-stability cold atom and ion standards already listed in the recommended radiations list are now available, that the frequencies of radiations of several new cold atom and ion species have also recently been measured, and that new improved values with substantially reduced uncertainties for a number of optical frequency standards based on gas cells have been determined, including the wavelength region of interest to optical telecommunications;
- that new femtosecond comb techniques have clear significance for relating the frequency of high-stability optical frequency standards to that of the frequency standard realizing the SI second, that these techniques represent a convenient measurement technique for providing traceability to the International System of Units (SI) and that comb technology also can provide frequency sources as well as a measurement technique;

recognizes comb techniques as timely and appropriate, and recommends further research to fully investigate the capability of the techniques;

welcomes validations now being made of comb techniques by comparison with other frequency chain techniques;

urges national metrology institutes and other laboratories to pursue the comb technique to the highest level of accuracy achievable and also to seek simplicity so as to encourage widespread application;

recommends

- that the list of recommended radiations given by the CIPM in 1997 (Recommendation 1 (CI-1997)) be replaced by the list of radiations given below*, including
  - updated frequency values for cold Ca atom, H atom and the trapped Sr^+ ion,
  - frequency values for new cold ion species including trapped Hg^+ ion, trapped In^+ ion and trapped Yb^+ ion,
  - updated frequency values for Rb-stabilized lasers, I_2-stabilized Nd:YAG and He-Ne lasers, CH_4-stabilized He-Ne lasers and OsO_4-stabilized CO_2 lasers at 10 μm,
  - frequency values for standards relevant to the optical communications bands, including Rb- and C_2H_2-stabilized lasers.

. . .

* The list of recommended radiations, Recommendation 1 (CI-2002), is given in PV, **70**, 197-204 and *Metrologia*, 2003, **40**, 104-115.

■ Dose equivalent (PV, **70**, 205)

See also *J. Radiol. Prot.*, 2005, **25**, 97-100.

Recommendation 2

The International Committee for Weights and Measures,

considering that

- the current definition of the SI unit of dose equivalent (sievert) includes a factor "*N*" (product of any other multiplying factors) stipulated by the International Commission on Radiological Protection (ICRP), and
- both the ICRP and the International Commission on Radiation Units and Measurements (ICRU) have decided to delete this factor *N* as it is no longer deemed to be necessary, and
- the current SI definition of *H* including the factor *N* is causing some confusion,

decides to change the explanation in the brochure "Le Système International d'Unités (SI)" to the following:

The quantity dose equivalent *H* is the product of the absorbed dose *D* of ionizing radiation and the dimensionless factor *Q* (quality factor) defined as a function of linear energy transfer by the ICRU:

$$H = Q \cdot D.$$

Thus, for a given radiation, the numerical value of *H* in joules per kilogram may differ from that of *D* in joules per kilogram depending on the value of *Q.*

The Committee further **decides** to maintain the final sentence in the explanation as follows:

In order to avoid any risk of confusion between the absorbed dose *D* and the dose equivalent *H*, the special names for the respective units should be used, that is, the name gray should be used instead of joules per kilogram for the unit of absorbed dose *D* and the name sievert instead of joules per kilogram for the unit of dose equivalent *H.*

CIPM, 2003

■ **Revision of the *Mise en Pratique* list of recommended radiations** (PV*,* **71***,* 146 and *Metrologia*, 2004, **41**, 99-100)

Recommendation 1

The International Committee for Weights and Measures,

considering that

- improved frequency values for radiations of some high-stability cold ion standards already documented in the recommended radiations list have recently become available;
- improved frequency values for the infra-red gas-cell-based optical frequency standard in the optical telecommunications region, already documented in the recommended radiations list, have been determined;
- femtosecond comb-based frequency measurements for certain iodine gas-cell standards on the subsidiary recommended source list have recently been made for the first time, leading to significantly reduced uncertainty;

proposes that the *recommended radiation* list be revised to include the following:

- updated frequency values for the single trapped $^{88}Sr^+$ ion quadrupole transition and the single trapped $^{171}Yb^+$ octupole transition;
- an updated frequency value for the C_2H_2-stabilized standard at 1.54 μm;
- updated frequency values for the I_2-stabilized standards at 543 nm and 515 nm.

22nd CGPM, 2003

■ **Symbol for the decimal marker** (CR, 381 and *Metrologia*, 2004, **41**, 104)

Resolution 10

The 22nd General Conference,

considering that

- a principal purpose of the International System of Units (SI) is to enable values of quantities to be expressed in a manner that can be readily understood throughout the world,
- the value of a quantity is normally expressed as a number times a unit,
- often the number in the expression of the value of a quantity contains multiple digits with an integral part and a decimal part,
- in Resolution 7 of the 9th General Conference, 1948, it is stated that “In numbers, the comma (French practice) or the dot (British practice) is used only to separate the integral part of numbers from the decimal part”,
- following a decision of the International Committee made at its 86th meeting (1997), the International Bureau of Weights and Measures now uses the dot (point on the line) as the decimal marker in all the English language versions of its publications, including the English text of the SI Brochure (the definitive international reference on the SI), with the comma (on the line) remaining the decimal marker in all of its French language publications,
- however, some international bodies use the comma on the line as the decimal marker in their English language documents,

- furthermore, some international bodies, including some international standards organizations, specify the decimal marker to be the comma on the line in all languages,
- the prescription of the comma on the line as the decimal marker is in many languages in conflict with the customary usage of the point on the line as the decimal marker in those languages,
- in some languages that are native to more than one country, either the point on the line or the comma on the line is used as the decimal marker depending on the country, while in some countries with more than one native language, either the point on the line or comma on the line is used depending on the language,

declares that the symbol for the decimal marker shall be either the point on the line or the comma on the line,

reaffirms that "Numbers may be divided in groups of three in order to facilitate reading; neither dots nor commas are ever inserted in the spaces between groups", as stated in Resolution 7 of the 9th CGPM, 1948.

CIPM, 2005

■ Clarification of the definition of the kelvin, unit of thermodynamic temperature (PV, **73**, 235 and *Metrologia*, 2006, **43**, 177-178)*

* The kelvin was redefined by the 26th CGPM in 2018 (Resolution 1, see p. 197).

Recommendation 2

The International Committee for Weights and Measures (CIPM),

considering

- that the kelvin, unit of thermodynamic temperature, is defined as the fraction 1/273.16 of the thermodynamic temperature of the triple point of water,
- that the temperature of the triple point depends on the relative amount of isotopes of hydrogen and oxygen present in the sample of water used,
- that this effect is now one of the major sources of the observed variability between different realizations of the water triple point,

decides

- that the definition of the kelvin refer to water of a specified isotopic composition,
- that this composition be:

  0.000 155 76 mole of ^{2}H per mole of ^{1}H,

  0.000 379 9 mole of ^{17}O per mole of ^{16}O, and

  0.002 005 2 mole of ^{18}O per mole of ^{16}O,

which is the composition of the International Atomic Energy Agency reference material Vienna Standard Mean Ocean Water (VSMOW), as recommended by IUPAC in "Atomic Weights of the Elements: Review 2000".

- that this composition be stated in a note attached to the definition of the kelvin in the SI brochure as follows:

  "This definition refers to water having the isotopic composition defined exactly by the following amount of substance ratios: 0.000 155 76 mole of ^{2}H per mole of ^{1}H, 0.000 379 9 mole of ^{17}O per mole of ^{16}O and 0.002 005 2 mole of ^{18}O per mole of ^{16}O".

■ **Revision of the *Mise en pratique* list of recommended radiations** (PV, **73,** 236 and *Metrologia*, 2006, **43**, 178)

Recommendation 3

The International Committee for Weights and Measures (CIPM),

considering that:

- improved frequency values for radiations of some high-stability cold ion and cold atom standards already documented in the recommended radiations list have recently become available;
- improved frequency values for the infra-red gas-cell-based optical frequency standard in the optical telecommunications region, already documented in the recommended radiations list, have been determined;
- improved frequency values for certain iodine gas-cell standard, already documented in the subsidiary recommended source list, have been determined;
- frequencies of new cold atoms, of atoms in the near-infrared region and of molecules in the optical telecommunications region have been determined by femtosecond comb-based frequency measurements for the first time;

decides that the list of *recommended radiations* be revised to include the following:

- updated frequency values for the single trapped $^{88}Sr^{+}$ ion quadrupole transition, the single trapped $^{199}Hg^{+}$ quadrupole transition and the single trapped $^{171}Yb^{+}$ quadrupole transition;
- an updated frequency value for the Ca atom transition;
- an updated frequency value for the C_2H_2-stabilized standard at 1.54 μm;
- an updated frequency value for the I_2-stabilized standard at 515 nm;
- the addition of the ^{87}Sr atom transition at 698 nm;
- the addition of the ^{87}Rb atom two-photon transitions at 760 nm;
- the addition of the $^{12}C_2H_2$ ($\nu1 + \nu3$) band and the $^{13}C_2H_2$ ($\nu1 + \nu3$) and ($\nu1 + \nu3 + \nu4 + \nu5$) bands at 1.54 μm.

CIPM, 2006

■ **Concerning secondary representations of the second** (PV, **74,** 249 and *Metrologia*, 2007, **44**, 97)

Recommendation 1

The International Committee for Weights and Measures (CIPM),

considering that

- a common list of “Recommended values of standard frequencies for applications including the practical realization of the metre and secondary representations of the second” shall be established,
- the CCL/CCTF Joint Working Group (JWG) on the *Mise en Pratique* of the Definition of the Metre and the Secondary Representations of the Second in its meeting at the International Bureau of Weights and Measures (BIPM) in September 2005 discussed possible candidates to be included in this list for secondary representations of the second,
- the CCL/CCTF JWG reviewed and updated the values for the Hg ion, Sr ion, Yb ion, and the Sr neutral atom transition frequencies in its session in September 2006,
- the CCTF in its Recommendation CCTF 1 (2004) already recommended the unperturbed ground-state hyperfine quantum transition frequency of 87Rb as a secondary representation of the second;

recommends that the following transition frequencies shall be used as secondary representations of the second and be included into the new list of “Recommended values of standard frequencies for applications including the practical realization of the metre and secondary representations of the second”

- the unperturbed ground-state hyperfine quantum transition of ^{87}Rb with a frequency of $f_{^{87}\text{Rb}}$ = 6 834 682 610.904 324 Hz and an estimated relative standard uncertainty of 3×10^{-15},
- the unperturbed optical 5s $^2S_{1/2}$ – 4d $^2D_{5/2}$ transition of the $^{88}Sr^+$ ion with a frequency of $f_{^{88}\text{Sr}^+}$ = 444 779 044 095 484 Hz and a relative uncertainty of 7×10^{-15},
- the unperturbed optical 5d^{10} 6s $^2S_{1/2}$ (F = 0) – 5d^9 6s^2 $^2D_{5/2}$ (F = 2) transition of the $^{199}Hg^+$ ion with a frequency of $f_{^{199}\text{Hg}^+}$ = 1 064 721 609 899 145 Hz and a relative standard uncertainty of 3×10^{-15},
- the unperturbed optical 6s $^2S_{1/2}$ (F = 0) – 5d $^2D_{3/2}$ (F = 2) transition of the $^{171}Yb^+$ ion with a frequency of $f_{^{171}\text{Yb}^+}$ = 688 358 979 309 308 Hz and a relative standard uncertainty of 9×10^{-15},
- the unperturbed optical transition 5s^2 $^1S_0$ – 5s 5p $^3P_0$ of the ^{87}Sr neutral atom with a frequency of $f_{^{87}\text{Sr}}$ = 429 228 004 229 877 Hz and a relative standard uncertainty of 1.5×10^{-14}.

CIPM, 2007

■ Revision of the Mise en pratique list of recommended radiations (PV, **75,** 185)

Recommendation 1

The International Committee for Weights and Measures,

considering that:

- improved frequency values of molecules in the optical telecommunications region, already documented in the list of standard frequencies, have been determined by femtosecond comb-based frequency measurements;
- frequencies of molecules in the optical telecommunications region have been determined by femtosecond comb-based frequency measurements for the first time;
- frequencies of certain iodine gas-cell absorptions close to the 532 nm optical frequency standard have been determined by femtosecond comb-based frequency measurements for the first time;

proposes that the list of standard frequencies be revised to include the following:

- an updated list of frequency values for the $^{12}C_2H_2$ (ν1 + ν3) band at 1.54 µm;
- the addition of frequency values for the $^{12}C_2HD$ ($2\nu_1$) band at 1.54 µm;
- the addition of frequency values for the hyperfine components of the P(142) 37-0, R(121) 35-0 and R(85) 33-0 iodine transitions at 532 nm.

23rd CGPM, 2007

■ On the revision of the mise en pratique of the definition of the metre and the development of new optical frequency standards (CR, 431)

Resolution 9

The 23rd General Conference,

considering that:

- there have been rapid and important improvements in the performance of optical frequency standards,
- femtosecond comb techniques are now used routinely for relating optical and microwave radiations at a single location,
- National Metrology Institutes (NMIs) are working on comparison techniques for optical frequency standards over short distances,
- remote comparison techniques need to be developed at an international level so that optical frequency standards can be compared,

welcomes

- the activities of the Joint Working Group of the Consultative Committee for Length and the Consultative Committee for Time and Frequency to review the frequencies of optically-based representations of the second,
- the additions to the *mise en pratique* of the definition of the metre and to the list of recommended radiations made by the International Committee in 2002, 2003, 2005, 2006, and 2007,
- the initiative taken by the International Bureau of Weights and Measures (BIPM) to raise the issue of how to compare optical frequency standards,

recommends that:

- NMIs commit resources to the development of optical frequency standards and their comparison,
- the BIPM works toward the coordination of an international project with the participation of NMIs, oriented to the study of the techniques which could serve to compare optical frequency standards.

■ Clarification of the definition of the kelvin, unit of thermodynamic temperature (CR, 432)

The kelvin was redefined by the 26th CGPM in 2018 (Resolution 1, see p. 197).

Resolution 10

The 23rd General Conference,

considering

- that the kelvin, unit of thermodynamic temperature, is defined as the fraction 1/273.16 of the thermodynamic temperature of the triple point of water,
- that the temperature of the triple point depends on the relative amount of isotopes of hydrogen and oxygen present in the sample of water used,
- that this effect is now one of the major sources of the observed variability between different realizations of the water triple point,

notes and welcomes the decision by the International Committee for Weights and Measures in October 2005, on the advice of the Consultative Committee for Thermometry, that

- the definition of the kelvin refers to water of a specified isotopic composition,
- this composition be:

  0.000 155 76 mole of ^{2}H per mole of ^{1}H,

  0.000 379 9 mole of ^{17}O per mole of ^{16}O, and

  0.002 005 2 mole of ^{18}O per mole of ^{16}O,

which is the composition of the International Atomic Energy Agency reference material Vienna Standard Mean Ocean Water (VSMOW), as recommended by the International Union of Pure and Applied Chemistry in "Atomic Weights of the Elements: Review 2000",

- this composition be stated in a note attached to the definition of the kelvin in the SI Brochure as follows:

  "This definition refers to water having the isotopic composition defined by the following amount-of-substance ratios: 0.000 155 76 mole of ^{2}H per mole of ^{1}H, 0.000 379 9 mole of ^{17}O per mole of ^{16}O and 0.002 005 2 mole of ^{18}O per mole of ^{16}O".

■ On the possible redefinition of certain base units of the International System of Units (SI) (CR, 434)

The 26th CGPM in 2018 (Resolution 1, see p. 197) finally approved the revision of the SI.

Resolution 12

The 23rd General Conference,

considering

- that, for many years, National Metrology Institutes (NMIs) as well as the International Bureau of Weights and Measures (BIPM) have made considerable efforts to advance and improve the International System of Units (SI) by extending the frontiers of metrology so that the SI base units could be defined in terms of the invariants of nature - the fundamental physical constants,
- that, of the seven base units of the SI, only the kilogram is still defined in terms of a material artefact - the international prototype of the kilogram (2nd CGPM, 1889, 3rd CGPM, 1901) and that the definitions of the ampere, mole and candela depend on the kilogram,
- Resolution 7 of the 21st General Conference (1999) which recommended that "national laboratories continue their efforts to refine experiments that link the unit of mass to fundamental or atomic constants with a view to a future redefinition of the kilogram",
- the many advances, made in recent years, in experiments which relate the mass of the international prototype to the Planck constant h or the Avogadro constant N_A,
- initiatives to determine the value of a number of relevant fundamental constants, including work to redetermine the Boltzmann constant k_B,
- that as a result of recent advances, there are significant implications for, and potential benefits from, redefinitions of the kilogram, the ampere, the kelvin and the mole,
- Recommendation 1 of the International Committee (C1-2005) at its meeting in October 2005, and various Recommendations of Consultative Committees on the subject of a redefinition of one or more of the base units of the SI,

noting

- that any changes in definitions of units of the SI must be constrained by self-consistency,
- that it is desirable that definitions of the base units should be easily understood,
- the work of the International Committee and the Consultative Committees,
- the need to monitor the results of relevant experiments,
- the importance of soliciting comments and contributions from the wider scientific and user communities, and
- the decision of the International Committee in 2005 to approve, in principle, the preparation of new definitions of the kilogram, ampere, kelvin and the possibility of redefining the mole,

recommends that National Metrology Institutes and the BIPM

- pursue the relevant experiments so that the International Committee can come to a view on whether it may be possible to redefine the kilogram, the ampere, the kelvin, and the mole using fixed values of the fundamental constants at the time of the 24th General Conference (2011),
- should, together with the International Committee, its Consultative Committees, and appropriate working groups, work on practical ways of realizing any new definitions based on fixed values of the fundamental constants, prepare a mise en pratique for each of them, and consider the most appropriate way of explaining the new definitions to users,
- initiate awareness campaigns to alert user communities to the possibility of redefinitions and that the technical and legislative implications of such redefinitions and their practical realizations be carefully discussed and considered,

and requests the International Committee to report on these issues to the 24th General Conference in 2011 and to undertake whatever preparations are considered necessary so that, if the results of experiments are found to be satisfactory and the needs of users met, formal proposals for changes in the definitions of the kilogram, ampere, the kelvin and mole can be put to the 24th General Conference.

CIPM, 2009

■ Updates to the list of standard frequencies (PV, **77,** 235)

Recommendation 2

The International Committee for Weights and Measures (CIPM),

considering that

- a common list of "Recommended values of standard frequencies for applications including the practical realization of the metre and secondary representations of the second" has been established;
- the CCL-CCTF Frequency Standards Working Group (FSWG) has reviewed several promising candidates for inclusion in the list;

recommends

that the following transition frequencies shall be included or updated in the list of recommended standard frequencies:

- the unperturbed optical transition $5s^2\ ^1S_0 – 5s\ 5p\ ^3P_0$ of the ^{87}Sr neutral atom with a frequency of f = 429 228 004 229 873.7 Hz and a relative standard uncertainty of 1×10^{-15} (this radiation is already endorsed by the CIPM as a secondary representation of the second);
- the unperturbed optical transition $5s^2\ ^1S_0 – 5s\ 5p\ ^3P_0$ of the ^{88}Sr neutral atom with a frequency of f = 429 228 066 418 012 Hz and a relative standard uncertainty of 1×10^{-14};
- the unperturbed optical transition $4s\ ^2S_{1/2} – 3d\ ^2D_{5/2}$ of the $^{40}Ca^+$ ion with a frequency of f = 411 042 129 776 393 Hz and a relative standard uncertainty of 4×10^{-14};
- the unperturbed optical transition $^2S_{1/2}$ (F = 0) – $^2F_{7/2}$ (F = 3, m_F = 0) of the $^{171}Yb^+$ ion with a frequency of f = 642 121 496 772 657 Hz and a relative standard uncertainty of 6×10^{-14};
- the unperturbed optical transition $6s^2\ ^1S_0$ (F = 1/2) – $6s\ 6p\ ^3P_0$ (F = 1/2) of the ^{171}Yb neutral atom with a frequency of f = 518 295 836 590 864 Hz and a relative standard uncertainty of 1.6×10^{-13}.

24th CGPM, 2011

■ On the possible future revision of the International System of Units, the SI (CR, 532)

The 26th CGPM in 2018 (Resolution 1, see p. 197) finally approved the revision of the SI.

Resolution 1

The General Conference on Weights and Measures (CGPM), at its 24th meeting,

considering

- the international consensus on the importance, value, and potential benefits of a redefinition of a number of units of the International System of Units (SI),
- that the national metrology institutes (NMIs) as well as the International Bureau of Weights and Measures (BIPM) have rightfully expended significant effort during the last several decades to advance the International System of Units (SI) by extending the frontiers of metrology so that SI base units can be defined in terms of the invariants of nature - the fundamental physical constants or properties of atoms,
- that a prominent example of the success of such efforts is the current definition of the SI unit of length, the metre (17th meeting of the CGPM, 1983, Resolution 1), which links it to an exact value of the speed of light in vacuum c, namely, 299 792 458 metre per second,
- that of the seven base units of the SI, only the kilogram is still defined in terms of a material artefact, namely, the international prototype of the kilogram (1st meeting of the CGPM, 1889, 3rd meeting of the CGPM, 1901), and that the definitions of the ampere, mole and candela depend on the kilogram,
- that although the international prototype has served science and technology well since it was sanctioned by the CGPM at its 1st meeting in 1889, it has a number of important limitations, one of the most significant being that its mass is not explicitly linked to an invariant of nature and in consequence its long-term stability is not assured,

- that the CGPM at its 21st meeting in 1999 adopted Resolution 7 in which it recommended that "national laboratories continue their efforts to refine experiments that link the unit of mass to fundamental or atomic constants with a view to a future redefinition of the kilogram",
- that many advances have been made in recent years in relating the mass of the international prototype to the Planck constant *h*, by methods which include watt balances and measurements of the mass of a silicon atom,
- that the uncertainties of all SI electrical units realized directly or indirectly by means of the Josephson and quantum Hall effects together with the SI values of the Josephson and von Klitzing constants K_J and R_K could be significantly reduced if the kilogram were redefined so as to be linked to an exact numerical value of *h*, and if the ampere were to be redefined so as to be linked to an exact numerical value of the elementary charge *e*,
- that the kelvin is currently defined in terms of an intrinsic property of water that, while being an invariant of nature, in practice depends on the purity and isotopic composition of the water used,
- that it is possible to redefine the kelvin so that it is linked to an exact numerical value of the Boltzmann constant *k*,
- that it is also possible to redefine the mole so that it is linked to an exact numerical value of the Avogadro constant N_A, and is thus no longer dependent on the definition of the kilogram even when the kilogram is defined so that it is linked to an exact numerical value of *h*, thereby emphasizing the distinction between amount of substance and mass,
- that the uncertainties of the values of many other important fundamental constants and energy conversion factors would be eliminated or greatly reduced if *h*, *e*, *k* and N_A had exact numerical values when expressed in SI units,
- that the General Conference, at its 23rd meeting in 2007, adopted Resolution 12 in which it outlined the work that should be carried out by the NMIs, the BIPM and the International Committee for Weights and Measures (CIPM) together with its Consultative Committees (CCs) so that new definitions of the kilogram, ampere, kelvin, and mole in terms of fundamental constants could be adopted,
- that, although this work has progressed well, not all the requirements set out in Resolution 12 adopted by the General Conference at its 23rd meeting in 2007 have been satisfied and so the International Committee for Weights and Measures is not yet ready to make a final proposal,
- that, nevertheless, a clear and detailed explanation of what is likely to be proposed can now be presented,

takes note of the intention of the International Committee for Weights and Measures to propose a revision of the SI as follows:

- the International System of Units, the SI, will be the system of units in which:
    - the ground state hyperfine splitting frequency of the caesium 133 atom $\Delta\nu(^{133}\text{Cs})_{\text{hfs}}$ is exactly 9 192 631 770 hertz,
    - the speed of light in vacuum *c* is exactly 299 792 458 metre per second,
    - the Planck constant *h* is exactly $6.626\ 06X \times 10^{-34}$ joule second*,
    - the elementary charge *e* is exactly $1.602\ 17X \times 10^{-19}$ coulomb,
    - the Boltzmann constant *k* is exactly $1.380\ 6X \times 10^{-23}$ joule per kelvin,
    - the Avogadro constant N_A is exactly $6.022\ 14X \times 10^{23}$ reciprocal mole,
    - the luminous efficacy K_{cd} of monochromatic radiation of frequency 540×10^{12} Hz is exactly 683 lumen per watt,

* The X digit appearing in the expression of the constants indicates that this digit was unknown at the time of the resolution.

where

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

(ii) the symbol X in this Draft Resolution represents one or more additional digits to be added to the numerical values of h, e, k, and N_A, using values based on the most recent CODATA adjustment,

from which it follows that the SI will continue to have the present set of seven base units, in particular

- the kilogram will continue to be the unit of mass, but its magnitude will be set by fixing the numerical value of the Planck constant to be equal to exactly 6.626 06X $\times$ 10^{-34} when it is expressed in the SI unit m^2 kg s^{-1}, which is equal to J s,
- the ampere will continue to be the unit of electric current, but its magnitude will be set by fixing the numerical value of the elementary charge to be equal to exactly 1.602 17X $\times$ 10^{-19} when it is expressed in the SI unit s A, which is equal to C,
- the kelvin will continue to be the unit of thermodynamic temperature, but its magnitude will be set by fixing the numerical value of the Boltzmann constant to be equal to exactly 1.380 6X $\times$ 10^{-23} when it is expressed in the SI unit m^2 kg s^{-2} K^{-1}, which is equal to J K^{-1},
- the mole will continue to be the unit of amount of substance of a specified elementary entity, which may be an atom, molecule, ion, electron, any other particle or a specified group of such particles, but its magnitude will be set by fixing the numerical value of the Avogadro constant to be equal to exactly 6.022 14X $\times$ 10^{23} when it is expressed in the SI unit mol^{-1}.

The General Conference on Weights and Measures

further notes that since

- the new definitions of the kilogram, ampere, kelvin and mole are intended to be of the explicit-constant type, that is, a definition in which the unit is defined indirectly by specifying explicitly an exact value for a well-recognized fundamental constant,
- the existing definition of the metre is linked to an exact value of the speed of light in vacuum, which is also a well-recognized fundamental constant,
- the existing definition of the second is linked to an exact value of a well-defined property of the caesium atom, which is also an invariant of nature,
- although the existing definition of the candela is not linked to a fundamental constant, it may be viewed as being linked to an exact value of an invariant of nature,
- it would enhance the understandability of the International System if all of its base units were of similar wording,

the International Committee for Weights and Measures will also propose

the reformulation of the existing definitions of the second, metre and candela in completely equivalent forms, which might be the following:

- the second, symbol s, is the unit of time; its magnitude is set by fixing the numerical value of the ground state hyperfine splitting frequency of the caesium 133 atom, at rest and at a temperature of 0 K, to be equal to exactly 9 192 631 770 when it is expressed in the SI unit s^{-1}, which is equal to Hz,
- the metre, symbol m, is the unit of length; its magnitude is set by fixing the numerical value of the speed of light in vacuum to be equal to exactly 299 792 458 when it is expressed in the SI unit m s^{-1},
- the candela, symbol cd, is the unit of luminous intensity in a given direction; its magnitude is set by fixing the numerical value of the luminous efficacy of monochromatic radiation of frequency 540 $\times$ 10^{12} Hz to be equal to exactly 683 when it is expressed in the SI unit m^{-2} kg^{-1} s^3 cd sr, or cd sr W^{-1}, which is equal to lm W^{-1}.

In this way, the definitions of all seven base units will be seen to follow naturally from the set of seven constants given above.

In consequence, on the date chosen for the implementation of the revision of the SI:

- the definition of the kilogram in force since 1889 based upon the mass of the international prototype of the kilogram (1st meeting of the CGPM, 1889, 3rd meeting of the CGPM, 1901) will be abrogated,
- the definition of the ampere in force since 1948 (9th meeting of the CGPM, 1948) based upon the definition proposed by the International Committee (CIPM, 1946, Resolution 2) will be abrogated,
- the conventional values of the Josephson constant K_{J-90} and of the von Klitzing constant R_{K-90} adopted by the International Committee (CIPM, 1988, Recommendations 1 and 2) at the request of the General Conference (18th meeting of the CGPM, 1987, Resolution 6) for the establishment of representations of the volt and the ohm using the Josephson and quantum Hall effects, respectively, will be abrogated,
- the definition of the kelvin in force since 1967/68 (13th meeting of the CGPM, 1967/68, Resolution 4) based upon a less explicit, earlier definition (10th meeting of the CGPM, 1954, Resolution 3) will be abrogated,
- the definition of the mole in force since 1971 (14th meeting of the CGPM, 1971, Resolution 3) based upon a definition whereby the molar mass of carbon 12 had the exact value 0.012 kg mol^{-1} will be abrogated,
- the existing definitions of the metre, second and candela in force since they were adopted by the CGPM at its 17th (1983, Resolution 1), 13th (1967/68, Resolution 1) and 16th (1979, Resolution 3) meetings, respectively, will be abrogated.

The General Conference on Weights and Measures

further notes that on the same date

- the mass of the international prototype of the kilogram $m(K)$ will be 1 kg but with a relative uncertainty equal to that of the recommended value of h just before redefinition and that subsequently its value will be determined experimentally,
- that the magnetic constant (permeability of vacuum) μ_0 will be $4\pi \times 10^{-7}$ H m^{-1} but with a relative uncertainty equal to that of the recommended value of the fine-structure constant alpha and that subsequently its value will be determined experimentally,
- that the thermodynamic temperature of the triple point of water T_{TPW} will be 273.16 K but with a relative uncertainty equal to that of the recommended value of *k* just before redefinition and that subsequently its value will be determined experimentally,
- that the molar mass of carbon 12 $M(^{12}C)$ will be 0.012 kg mol^{-1} but with a relative uncertainty equal to that of the recommended value of $N_A h$ just before redefinition and that subsequently its value will be determined experimentally.

The General Conference on Weights and Measures

encourages

- researchers in national metrology institutes, the BIPM and academic institutions to continue their efforts and make known to the scientific community in general and to CODATA in particular, the outcome of their work relevant to the determination of the constants *h*, *e*, *k*, and N_A, and
- the BIPM to continue its work on relating the traceability of the prototypes it maintains to the international prototype of the kilogram, and in developing a pool of reference standards to facilitate the dissemination of the unit of mass when redefined,

invites

- CODATA to continue to provide adjusted values of the fundamental physical constants based on all relevant information available and to make the results known to the International Committee through its Consultative Committee for Units since these CODATA values and uncertainties will be those used for the revised SI,

- the CIPM to make a proposal for the revision of the SI as soon as the recommendations of Resolution 12 of the 23rd meeting of the General Conference are fulfilled, in particular the preparation of *mises en pratique* for the new definitions of the kilogram, ampere, kelvin and mole,
- the CIPM to continue its work towards improved formulations for the definitions of the SI base units in terms of fundamental constants, having as far as possible a more easily understandable description for users in general, consistent with scientific rigour and clarity,
- the CIPM, the Consultative Committees, the BIPM, the OIML and National Metrology Institutes significantly to increase their efforts to initiate awareness campaigns aimed at alerting user communities and the general public to the intention to redefine various units of the SI and to encourage consideration of the practical, technical, and legislative implications of such redefinitions, so that comments and contributions can be solicited from the wider scientific and user communities.

■ On the revision of the mise en pratique of the metre and the development of new optical frequency standards (CR*,* 546)

Resolution 8

The General Conference on Weight and Measures (CGPM), at its 24th meeting,

considering that

- there have been rapid and important improvements in the performance of optical frequency standards,
- national metrology institutes are working on comparison techniques for optical frequency standards over short distances,
- remote comparison techniques need to be developed at an international level so that optical frequency standards can be compared,

welcomes

- the activities of the joint working group of the CCTF and the CCL to review the frequencies of optically-based representations of the second,
- the additions made by the CIPM in 2009 to the common list of "Recommended values of standard frequencies for applications including the practical realization of the metre and secondary representations of the second",
- the establishment of a CCTF working group on Coordination of the Development of Advanced Time and Frequency Transfer Techniques,

recommends that

- NMIs commit resources to the development of optical frequency standards and their comparison,
- the BIPM supports the coordination of an international project with the participation of NMIs, oriented to the study of the techniques which could serve to compare optical frequency standards**.**

CIPM, 2013

■ Updates to the list of standard frequencies (PV*,* **81,** 144)

Recommendation 1

The International Committee for Weights and Measures (CIPM),

considering that

- a common list of “Recommended values of standard frequencies for applications including the practical realization of the metre and secondary representations of the second” has been established,
- the CCL-CCTF Frequency Standards Working Group (FSWG) has reviewed several candidates for inclusion into the list,

recommends the following changes to the list of "Recommended values of standard frequencies for applications including the practical realization of the metre and secondary representations of the second":

- that the following transition frequency be added to the list:
  - the unperturbed optical transition $6s^2\ {}^1S_0 – 6s\ 6p\ {}^3P_0$ of the ^{199}Hg neutral atom with a frequency of 1 128 575 290 808 162 Hz and an estimated relative standard uncertainty of 1.7×10^{-14};
- that the following transition frequencies be updated in the list:
  - the unperturbed optical transition $4s\ {}^2S_{1/2} – 3d\ {}^2D_{5/2}$ of the $^{40}Ca^+$ ion with a frequency of 411 042 129 776 395 Hz and an estimated relative standard uncertainty of 1.5×10^{-14};
  - the unperturbed optical transition 1S – 2S of the ^{1}H neutral atom with a frequency of 1 233 030 706 593 518 Hz and an estimated relative standard uncertainty of 1.2×10^{-14};

Note: This frequency corresponds to half of the energy difference between the 1S and 2S states;

- that the following transition frequencies be updated in the list and endorsed as secondary representations of the second:
  - the unperturbed optical transition $6s\ {}^2S_{1/2} – 4f\ {}^{13}6s^2\ {}^2F_{7/2}$ of the $^{171}Yb^+$ ion (octupole) with a frequency of 642 121 496 772 645.6 Hz and an estimated relative standard uncertainty of 1.3×10^{-15};
  - the unperturbed optical transition $6s^2\ {}^1S_0 – 6s\ 6p\ {}^3P0$ of the ^{171}Yb neutral atom with a frequency of 518 295 836 590 865.0 Hz and an estimated relative standard uncertainty of 2.7×10^{-15};
- that the following transition frequency be added to the list and as a secondary representation of the second:
  - the unperturbed optical transition $3s^2\ {}^1S_0 – 3s\ 3p\ {}^3P_0$ of the $^{27}Al^+$ ion with a frequency of 1 121 015 393 207 857.3 Hz and an estimated relative standard uncertainty of 1.9×10^{-15};
- that the following transition frequencies be updated in the list and as secondary representations of the second:
  - the unperturbed optical transition $5d\ {}^{10}6s\ {}^2S_{1/2} – 5d\ {}^96s^2\ {}^2D_{5/2}$ of the $^{199}Hg^+$ ion with a frequency of 1 064 721 609 899 145.3 Hz and an estimated relative standard uncertainty of 1.9×10^{-15};
  - the unperturbed optical transition $6s\ {}^2S_{1/2}$ ($F = 0$, $m_F = 0$) – $5d\ {}^2D_{3/2}$ ($F = 2$, $m_F = 0$) of the 171Yb+ ion (quadrupole) with a frequency of 688 358 979 309 307.1 Hz and an estimated relative standard uncertainty of 3×10^{-15};
  - the unperturbed optical transition $5s\ {}^2S_{1/2} – 4d\ {}^2D_{5/2}$ of the $^{88}Sr^+$ ion with a frequency of 444 779 044 095 485.3 Hz and an estimated relative standard uncertainty of 4.0×10^{-15};
  - the unperturbed optical transition $5s^2\ {}^1S_0 – 5s5p\ {}^3P_0$ of the ^{87}Sr neutral atom with a frequency of 429 228 004 229 873.4 Hz and an estimated relative standard uncertainty of 1×10^{-15};
- that the following transition frequency be updated as a secondary representation of the second:
  - the unperturbed ground - state hyperfine transition of ^{87}Rb with a frequency of 6 834 682 610.904 312 Hz and an estimated relative standard uncertainty of 1.3×10^{-15}.

Note: The value of the estimated standard uncertainty is assumed to correspond to a confidence level of 68 %. However, given the very limited number of available data there is a possibility that in hindsight this might not prove to be exact.

25th CGPM, 2014

■ **On the future revision of the International System of Units, the SI** (CR, 416 and *Metrologia*, 2015, **52**, 155)

The 26th CGPM in 2018 (Resolution 1, see p. 197) finally approved the revision of the SI.

Resolution 1

The General Conference on Weights and Measures (CGPM), at its 25th meeting,

recalling

- Resolution 1 adopted by the CGPM at its 24th meeting (2011), which takes note of the intention of the International Committee for Weights and Measures (CIPM) to propose a revision of the SI that links the definitions of the kilogram, ampere, kelvin, and mole to exact numerical values of the Planck constant h, elementary charge e, Boltzmann constant k, and Avogadro constant N_A, respectively, and which revises the way the SI is defined including the wording of the definitions of the SI units for time, length, mass, electric current, thermodynamic temperature, amount of substance, and luminous intensity so that the reference constants on which the SI is based are clearly apparent,
- the many benefits summarized in Resolution 1 that will accrue to science, technology, industry, and commerce from such a revision, especially from linking the kilogram to an invariant of nature rather than to the mass of a material artefact, thereby ensuring its long-term stability,
- Resolution 7 adopted by the CGPM at its 21st meeting (1999), which encourages work at the National Metrology Institutes (NMIs) that can lead to such a redefinition of the kilogram,
- Resolution 12 adopted by the CGPM at its 23rd meeting (2007), which outlines the work that should be carried out by the NMIs, the International Bureau of Weights and Measures (BIPM), and the CIPM together with its Consultative Committees (CCs) that could enable the planned revision of the SI to be adopted by the CGPM,

considering that there has been significant progress in completing the necessary work, including

- the acquisition of relevant data and their analysis by the Committee on Data for Science and Technology (CODATA) to obtain the required values of h, e, k, and N_A,
- establishment by the BIPM of an ensemble of reference standards of mass to facilitate the dissemination of the unit of mass in the revised SI,
- the preparation of mises-en-pratique for the new definitions of the kilogram, ampere, kelvin, and mole,

noting that further work by the Consultative Committee for Units (CCU), the CIPM, the BIPM, the NMIs and the CCs should focus on

- awareness campaigns to alert user communities as well as the general public to the proposed revision of the SI,
- the preparation of the 9th edition of the SI Brochure that presents the revised SI in a way that can be understood by a diverse readership without compromising scientific rigour,

that despite this progress the data do not yet appear to be sufficiently robust for the CGPM to adopt the revised SI at its 25th meeting,

encourages

- continued effort in the NMIs, the BIPM, and academic institutions to obtain data relevant to the determination of h, e, k, and N_A with the requisite uncertainties,
- the NMIs to continue acting through the CCs to discuss and review this data,
- the CIPM to continue developing a plan to provide the path via the Consultative Committees and the CCU for implementing Resolution 1 adopted by the CGPM at its 24th meeting (2011), and
- continued effort by the CIPM, together with its Consultative Committees, the NMIs, the BIPM, and other organizations such as the International Organization of Legal Metrology (OIML), to complete all work necessary for the CGPM at its 26th meeting to adopt a resolution that would replace the current SI with the revised SI, provided the amount of data, their uncertainties, and level of consistency are deemed satisfactory.

CIPM, 2015

■ Updates to the list of standard frequencies (PV, **83,** 207)

Further updates are available on the BIPM website.

Recommendation 2

The International Committee for Weights and Measures (CIPM),

considering

- a common list of "Recommended values of standard frequencies for applications including the practical realization of the metre and secondary representations of the second" has been established,
- the CCL-CCTF Frequency Standards Working Group (WGFS) has reviewed several candidates for updating the list,

recommends

that the following transition frequencies shall be updated in the list of recommended values of standard frequencies:

- the unperturbed optical transition $6s^2\ ^1S_0 - 6s6p\ ^3P_0$ of the ^{199}Hg neutral atom with a frequency of $f_{199\text{Hg}}$ = 1 128 575 290 808 154.8 Hz and an estimated relative standard uncertainty of 6×10^{-16};
- the unperturbed optical transition $6s\ ^2S_{1/2} - 4f^{13}\ 6s^2\ ^2F_{7/2}$ of the $^{171}Yb^+$ ion with a frequency of $f_{171\text{Yb+}}$ (octupole) = 642 121 496 772 645.0 Hz and an estimated relative standard uncertainty of 6×10^{-16} (this radiation is already endorsed by the CIPM as a secondary representation of the second);
- the unperturbed optical transition $6s\ ^2S_{1/2}$ (F = 0, m_F = 0) – $5d\ ^2D_{3/2}$ (F = 2, m_F = 0) of the $^{171}Yb^+$ ion with a frequency of $f_{171\text{Yb+}}$ (quadrupole) = 688 358 979 309 308.3 Hz and an estimated relative standard uncertainty of 6×10^{-16} (this radiation is already endorsed by the CIPM as a secondary representation of the second);
- the unperturbed optical transition $5s\ ^2S_{1/2} - 4d\ ^2D_{5/2}$ of the $^{88}Sr^+$ ion with a frequency of $f_{88\text{Sr+}}$ = 444 779 044 095 486.6 Hz and an estimated relative standard uncertainty of 1.6×10^{-15} (this radiation is already endorsed by the CIPM as a secondary representation of the second);
- the unperturbed optical transition $4s\ ^2S_{1/2} - 3d\ ^2D_{5/2}$ of the $^{40}Ca^+$ ion with a frequency of $f_{40\text{Ca+}}$ = 411 042 129 776 398.4 Hz and an estimated relative standard uncertainty of 1.2×10^{-14};
- the unperturbed optical transition 1S – 2S of the 1H neutral atom with a frequency of $f_{1\text{H}}$ = 1 233 030 706 593 514 Hz and an estimated relative standard uncertainty of 9×10^{-15}.

Note: This frequency corresponds to half of the energy difference between the 1S and 2S states;

- the unperturbed optical transition $5s^2\ ^1S_0 - 5s5p\ ^3P_0$ of the ^{87}Sr neutral atom with a frequency of $f_{87\text{Sr}}$ = 429 228 004 229 873.2 Hz and an estimated relative standard uncertainty of 5×10^{-16} (this radiation is already endorsed by the CIPM as a secondary representation of the second);
- the unperturbed optical transition $6s^2\ ^1S_0 - 6s6p\ ^3P_0$ of the ^{171}Yb neutral atom with a frequency of $f_{171\text{Yb}}$ = 518 295 836 590 864.0 Hz and an estimated relative standard uncertainty of 2×10^{-15} (this radiation is already endorsed by the CIPM as a secondary representation of the second);
- the unperturbed ground-state hyperfine transition of ^{87}Rb with a frequency of $f_{87\text{Rb}}$ = 6 834 682 610.904 310 Hz and an estimated relative standard uncertainty of 7×10^{-16} (this radiation is already endorsed by the CIPM as a secondary representation of the second).

and also **recommends**

that the following transition frequencies shall be included in the list of recommended values of standard frequencies:

- Absorbing molecule $^{127}I_2$, saturated absorption a_1 component, R(36) 32-0 transition.

The values f_{a1} = 564 074 632.42 MHz

λ_{a1} = 531 476 582.65 fm

with an estimated relative standard uncertainty of 1×10^{-10} apply to the radiation of a frequency-doubled diode DFB laser, stabilized with an iodine cell external to the laser.

- Absorbing atom ^{87}Rb $5S_{1/2}$ - $5P_{3/2}$ crossover between the d and f hyperfine components of the saturated absorption at 780 nm (D2 transition)

The values $f_{\text{d/f crossover}}$ = 384 227 981.9 MHz

$\lambda_{\text{d/f crossover}}$ = 780 246 291.6 fm

with an estimated relative standard uncertainty of 5×10^{-10} apply to the radiation of a tunable External Cavity Diode Laser, stabilized to the d/f crossover in a rubidium cell external to the laser.

Note: The value of the standard uncertainty is assumed to correspond to a confidence level of 68 %. However, given the limited availability of data there is a possibility that in hindsight this might not prove to be exact

CIPM, 2017

■ **On progress towards the possible redefinition of the SI** (PV, **85,** 101)

Decision 10

The International Committee for Weights and Measures (CIPM) welcomed recommendations regarding the redefinition of the SI from its Consultative Committees.

The CIPM noted that the agreed conditions for the redefinition are now met and decided to submit draft Resolution A to the 26th meeting of the General Conference on Weights and Measures (CGPM) and to undertake all other necessary steps to proceed with the planned redefinition of the kilogram, ampere, kelvin and mole.

26th CGPM, 2018

■ **On the revision of the International System of Units, the SI** (CR, in press and *Metrologia*, 2019, **56**, 022001)

Resolution 1

The General Conference on Weights and Measures (CGPM), at its 26th meeting,

considering

- the essential requirement for an International System of Units (SI) that is uniform and accessible world-wide for international trade, high-technology manufacturing, human health and safety, protection of the environment, global climate studies and the basic science that underpins all these,
- that the SI units must be stable in the long term, internally self-consistent and practically realizable being based on the present theoretical description of nature at the highest level,
- that a revision of the SI to meet these requirements was described in Resolution 1 of the 24th General Conference in 2011, adopted unanimously, that laid out in detail a new way of defining the SI based on a set of seven defining constants, drawn from the fundamental constants of physics and other constants of nature, from which the definitions of the seven base units are deduced,
- that the conditions set by the 24th General Conference, confirmed by the 25th General Conference, before such a revised SI could be adopted have now been met,

decides

that, effective from 20 May 2019, the International System of Units, the SI, is the system of units in which

- the unperturbed ground state hyperfine transition frequency of the caesium 133 atom $\Delta \nu_{\text{Cs}}$ is 9 192 631 770 Hz,
- the speed of light in vacuum c is 299 792 458 m/s,
- the Planck constant h is $6.626\ 070\ 15 \times 10^{-34}$ J s,
- the elementary charge e is $1.602\ 176\ 634 \times 10^{-19}$ C,

- the Boltzmann constant k is 1.380 649 × 10^{-23} J/K,
- the Avogadro constant N_A is 6.022 140 76 × 10^{23} mol^{-1},
- 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, and W, respectively, are related to the units second, metre, kilogram, ampere, kelvin, mole, and candela, with unit symbols s, m, kg, A, K, mol, and cd, respectively, according to Hz = s^{-1}, J = kg m^2 s^{-2}, C = A s, lm = cd m^2 m^{-2} = cd sr, and W = kg m^2 s^{-3}.

In making this decision, the General Conference notes the consequences as set out in Resolution 1 of the 24th General Conference in respect to the base units of the SI and confirms these in the following Appendices to this Resolution, which have the same force as the Resolution itself.

The General Conference invites the International Committee to produce a new edition of its Brochure *The International System of Units, SI* in which a full description of the SI is given.

Appendix 1. Abrogation of former definitions of the base units:

It follows from the new definition of the SI adopted above that

- the definition of the second in force since 1967/68 (13th meeting of the CGPM, Resolution 1) is abrogated,
- the definition of the metre in force since 1983 (17th meeting of the CGPM, Resolution 1), is abrogated,
- the definition of the kilogram in force since 1889 (1st meeting of the CGPM, 1889, 3rd meeting of the CGPM, 1901) based upon the mass of the international prototype of the kilogram is abrogated,
- the definition of the ampere in force since 1948 (9th meeting of the CGPM) based upon the definition proposed by the International Committee (CIPM, 1946, Resolution 2) is abrogated,
- the definition of the kelvin in force since 1967/68 (13th meeting of the CGPM, Resolution 4) is abrogated,
- the definition of the mole in force since 1971 (14th meeting of the CGPM, Resolution 3) is abrogated,
- the definition of the candela in force since 1979 (16th meeting of the CGPM, Resolution 3) is abrogated,
- the decision to adopt the conventional values of the Josephson constant K_{J-90} and of the von Klitzing constant R_{K-90} taken by the International Committee (CIPM, 1988, Recommendations 1 and 2) at the request of the General Conference (18th meeting of the CGPM, 1987, Resolution 6) for the establishment of representations of the volt and the ohm using the Josephson and quantum Hall effects, respectively, is abrogated.

Appendix 2. Status of constants previously used in the former definitions:

It follows from the new definition of the SI adopted above, and from the recommended values of the 2017 special CODATA adjustment on which the values of the defining constants are based, that at the time this Resolution was adopted

- the mass of the international prototype of the kilogram $m(K)$ is equal to 1 kg within a relative standard uncertainty equal to that of the recommended value of h at the time this Resolution was adopted, namely 1.0 × 10^{-8} and that in the future its value will be determined experimentally,
- the vacuum magnetic permeability μ_0 is equal to 4π × 10^{-7} H m^{-1} within a relative standard uncertainty equal to that of the recommended value of the fine-structure constant α at the time this Resolution was adopted, namely 2.3 × 10^{-10} and that in the future its value will be determined experimentally,

- the thermodynamic temperature of the triple point of water T_{TPW} is equal to 273.16 K within a relative standard uncertainty closely equal to that of the recommended value of *k* at the time this Resolution was adopted, namely 3.7×10^{-7}, and that in the future its value will be determined experimentally,
- the molar mass of carbon 12, $M(^{12}C)$, is equal to 0.012 kg mol^{-1} within a relative standard uncertainty equal to that of the recommended value of $N_A h$ at the time this Resolution was adopted, namely 4.5×10^{-10}, and that in the future its value will be determined experimentally.

Appendix 3. The base units of the SI

Starting from the definition of the SI adopted above in terms of fixed numerical values of the defining constants, definitions of each of the seven base units are deduced by taking, as appropriate, one or more of these defining constants to give the following set of definitions:

- The second, symbol s, is the SI unit of time. It is defined by taking the fixed numerical value of the caesium frequency $\Delta\nu_{Cs}$, the unperturbed ground-state hyperfine transition frequency of the caesium 133 atom, to be 9 192 631 770 when expressed in the unit Hz, which is equal to s^{-1}.
- The metre, symbol m, is the SI unit of length. It 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, where the second is defined in terms of the caesium frequency $\Delta\nu_{Cs}$.
- 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 kg m^2 s^{-1}, where the metre and the second are defined in terms of *c* and $\Delta\nu_{Cs}$.
- 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 $\Delta\nu_{Cs}$.
- 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 J K^{-1}, which is equal to kg m^2 s^{-2} K^{-1}, where the kilogram, metre and second are defined in terms of *h*, *c* and $\Delta\nu_{Cs}$.
- The mole, symbol mol, is the SI unit of amount of substance. One mole contains exactly $6.022\ 140\ 76 \times 10^{23}$ 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 amount of substance, symbol *n*, of a system is a measure of the number of specified elementary entities. An elementary entity may be an atom, a molecule, an ion, an electron, any other particle or specified group of particles.
- 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 540×10^{12} 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} s^3, where the kilogram, metre and second are defined in terms of *h*, *c* and $\Delta\nu_{Cs}$.