COOMET	COOMET RECOMMENDATION	**COOMET** R/GM/20:2024
	SCALES OF MEASUREMENTS. TERMS AND DEFINITIONS	

Approved in 19th meeting of COOMET Committee (20-21 May 2009, Baku, Azerbaijan).
Clarified and supplemented:
at the __ meeting of the COOMET Committee (______________________)

1 AREA OF APPLICATION

This recommendation establishes the basic terms and definitions of concepts necessary for the practical application of the theory of measurement scales in legislative and applied metrology.

The established terms are recommended to be used in all types of documentation and scientific and technical literature used in the performance of work in the field of metrology.

The terms defined by the present recommendation are placed in systemized order that reflects the system of concepts in the scales of measurements theory.

For every concept there is one term defined.

The part of term in round brackets can be omitted when using the term in documents on standardization. So the part of term out of round brackets represents its short form.

If the square brackets present in terminology statement, it means that the statement includes two terms with common elements. These terms are included in alphabetical index separately with the reference to corresponding statement number.

The definitions of terms can be modified by adding specific characteristics, by revealing the meaning of used terms, by pointing to objects that are bound with defined concept. But these modifications must not violate the general sense of concepts defined in present recommendations.

There are equivalents of defined by present recommendations terms in Russian (ru), German (de) and French (fr) languages.

After the main part of present recommendations there is alphabetical index of terms in English and alphabetical indexes of terms in Russian, German and French languages also. The basics of the scales of measurements theory that are important for better understanding the recommendations are presented in Appendix A.

The present recommendation extend and expand metrological terminology on the base of scales of measurements theory.

Recommended terms are printed in bold script, their short forms in alphabetical index are printed in light-face.

The previous version of the recommendation (COOMET R/GM/20:2009) was developed on the basis of RMG 83-2007 [1] and updated by supplementing the "Bibliography" with new documents (publications) [2-10] and correcting bibliographic references in the text with local notes, clarifications and additions.

2 BASIC PROVISIONS (TERMS AND DEFINITIONS)

2.1 General concepts

2.1.1 **Scale (of measurements)**
ru Шкала (измерений)
de Skala (der Messungen)
fr échelle (des Mesurages)

Representation of a set of different realizations of quantitative or qualitative property (or a combination of them) of an object as an accepted by agreement ordered number set or other system of logically related signs (designations).
Notes
1 The concept «scale of measurements» (scale) is not identical to the indication or display component (scale) of a measuring device.
2 There are five main different types of scales: of denominations, of an order, of differences (intervals), of ratios and absolute.
3 The examples of systems of related designations that compose scales of measurements are: set of marks or points to estimate the feature (or ability), set of designations (names) of colours, set of designations (names) of an object state, unity of classification symbols or concepts, set of points in
some model system of coordinates.
4 Scales of differences and ratios are combined inside the term «metric scales».
5 The scales can be one-dimensional and multi-dimensional qualitative, quantitative and combined properties (see Appendix A).

2.1.2 scale of a quantity
ru шкала величины
de Skala einer Gröβe
fr échelle d′ une grandeur

Scale of measurements of quantitative property.

2.1.3 specification for scale (of measurements)
ru спецификация шкалы измерений
de Spezifikation für skala der Messungen
fr specification d′ une échelle desmesurages

Accepted by agreement document containing semantic definition of a scale and (or) the description of rules and procedures for the scale realization (or unit if it does exist).
Notes
1 Some metric scales, e.g. scales of mass and length, are specified adequately by standard definitions of units of measurements.
2 Specifications of many (even metrical) scales contain some additional statements along with the definition of units of measurement. For example, the International Temperature Scale ITS-90 contains directions on reproduction of reference points. Specification for scale of light measurements includes not only the definition of luminous intensity (candela), but also tabulated function of spectral luminous efficiency of monochrome radiation on daylight vision.

2.1.4 elements of scale (of measurements)
ru элемент шкалы измерений
de Elemente von Skalen der Messungen
fr elements d′ une échelle des mesurages

Basic features that describe the scale of measurements: class of equivalence, zero, conventional zero, conventional unit of measurement, natural (dimensionless) unit of measurement, range of the scale, point of the scale.

2.1.5 type of scale (of measurements)
ru тип шкалы
de Skalatyp
fr тype d′ une échelle

Specific set of features on which scales of measurements can be classified. It describes the logical relations between different realizations of a measured property.

2.1.6 reproduction of scale (of measurements)
ru воспроизведение шкалы измерений
de Skalareproduction
fr reproduction de échelle des mesurages

Set of operations in order to reproduce scale of measurements (or a partial range of it) according to its specification.

2.1.7 transmission of scale (of measurements)
ru передача шкалы измерений
de Skalatranslation
fr transmission de échelle des mesurages

Bringing a scale (or a partial range of it) represented by the device under verification (calibration) to conformity with the scale represented by more accurate (reference) standard.

2.2 Types of scales of measurements

2.2.1 scale of denominations
ru шкала наименований
de Bezeichnungenscala
fr échelle d′ un dénominations

Scale of measurements of qualitative property which is fully described by relations of equivalence or difference in realizations of this property.
Notes
1 Sometimes the set of realizations of qualitative property can be ordered by closeness (similarity) of qualitative differences and (or) by quantitative differences in some subsets of property realizations. For example, scales of colour measurements are based on three-coordinate model of colour space in which colours are ordered by differences (qualitative feature) and luminosity (quantitative feature).
2 Scales of denominations have specific set of features: concepts of zero, unit of measurements and dimension have no sense and cannot be used; only isomorphic and homomorphic transformations are permitted; the specification for particular scale cannot be modified. In the most often case
the scale of denominations is defined by a row of “classes of equivalence”.

2.2.2 scale of an order
ru шкала порядка
de Ordnungskala
fr échelle d′ une order

Scale of measurements of quantitative property (quantity), which is fully described by relations of equivalence and ascending (descending) order of different realizations of this property.
Note
Scales of an order have specific set of features: concepts of unit of measurements and dimension do not exist and cannot be used; zero can exist but not necessarily; all monotone transformations are permitted; the specification for particular scale cannot be modified.

2.2.3 **scale of differences [intervals]**
ru шкала разностей [интервалов]
de Skala der Differenzen [Zwischenräume]
fr échelle d′ un différences [intervalles]

Scale of measurements of quantitative property (quantity), which is fully described by
relations of equivalence and order and by possibility to sumintervals of different realizations of this property.
Note
Scales of differences have specific features: zero and unit of measurements are defined by agreement; the concept of dimension can be applied; linear transformations are permitted; the specification for particular scale can be modified.

2.2.4 **scale of ratios**
ru шкала отношений
de Skala der Verhältnisse
fr échelle d′ un relations

Scale of measurements of quantitative property (quantity), which is fully described by relations of equivalence, order and proportionality of different realizations of this property. In some cases different realizations of the property can be summed.
Notes
1 Scales of ratios have specific set of features: natural zero exists; unit of measurements is defined by agreement; the concept of dimension can be applied; scaling transformations are permitted; the specification for particular scale can be modified.
2 Scales of ratios are called “proportional scales of ratios” (of the 1st type) if the summation operation cannot be defined because it has no sense. Scales of ratios are called “additive scales of ratios” (of the 2nd type) if the summation operation has sense and can be defined. For example, the scale of thermodynamic temperature is proportional, the scale of mass is additive.

2.2.5 **absolute scale**
ru абсолютная шкала
de Absolute Skala
fr échelle absolue

Scale of ratios (proportional or additive) of dimensionless quantity.
Notes
1 Absolute scales have specific set of features: natural zero and arithmetical unit of measurements exist and do not depend on chosen system of units; only identical transformations are permitted; the specification for particular scale can be modified.
2 The results of measurements in absolute scales can be presented not only in arithmetical units but also in percents, promille, bits, bytes, decibels (see logarithmic scales).
3 Units of absolute scales can be used in combination with dimensioned units of quantities, e.g. information transmission rate in bits per second.
4 Discrete (countable) scales are a particular sort of absolute scales, the result of measurement in them is expressed by number of particles, quanta or other objects that are equivalent in respect of realization of measured property. For example, scales for electrical charge of atomic nuclei, for number of quanta (in photochemistry), for amount of information. Sometimes some definite number of particles (quanta) is conventionally defined as a unit of measurement (with special denomination) in these scales, e.g. one mol – number of particles equal to Avogadro constant.

2.2.6 **absolute limited scale**
ru Абсолютная ограниченная шкала
de Absolute beschränkte Skala

fr échelle absolue limité

Absolute scale with range of quantities from zero to one (or to some other limit according to the specification).

2.2.7 **logarithmic scale**
ru логарифмическая шкала
de Logarithmen Skala
fr échelle logarithmique

Scale of measurements which is built by logarithmic transformation of measurable quantity.
Note
Usually systems of common or natural logarithms are used to build logarithmic scale; system of binary logarithms can be used also.

2.2.8 **logarithmic scale of differences**
ru логарифмическая шкала разностей
de Logarithmen Skala der Differenzen
fr échelle logarithmique du différences

Logarithmic scale which is the result of logarithmic transformation of a quantity described by scale of ratios or by intervals in scale of differences, i.e. the scale is defined by dependence L = log
(X/X0), where X is current and X0 is adopted by agreement reference value of transformable quantity.
Note
The choice of reference value X0 defines zero point of logarithmic scale of differences.

2.2.9 **logarithmic absolute scale**
ru логарифмическая абсолютная шкала
de Logarithmen absolute Skala
fr échelle logarithmique absolue

Logarithmic scale which is the result of logarithmic transformation L= log X of a dimensionless quantity X described by absolute scale.
Note
This sort of scales is also called logarithmic scale with floating zero.

2.2.10 **biophysical scale**
ru биофизическая шкала
de Biophysikalische Skala
fr échelle biophysique

Scale of measurements of a physical factor (stimulus) property which was modified so that the result of measurements of this property can be used to predict the level or character of reaction of biological object induced by this factor.

2.2.11 **one-dimensional scale**
ru одномерная шкала
de Eindimensionale Skala
fr échelle monodimensionale

Scale of measurements described by one parameter, in which the results of measurements are represented by one number or one sign (designation).

2.2.12 **multidimensional scale**

ru многомерная шкала
de Veildimensionale Skala
fr échelle multidimensional

Scale of measurements described by two or more parameters, in which the results of measurements are represented by blocks of two or more numbers or signs (designations).
Notes
1 Some properties can not be described by one parameter in principle. For example, electrical impedance and complex reflection coefficient are described by two parameters that represent two-dimensional scales. The colour is described by three coordinates in models of colours space that represent three-dimensional scales.
2 Multidimensional scales can be produced by combination of scales of different types.
3 Often in multidimensional scales some spatial or abstract system of special coordinates is established, e.g. for measurements of velocities and accelerations vectors, for geodesic coordinates the location and orientation angles of the directions (objects) in space.

2.3 Elements of scales

2.3.1 zero of a scale
ru нуль шкалы
de Skalanull
fr zéro d′ une échelle

Initial point in scales of order (some), of intervals, of ratios and absolute.
Note
Zero can be either natural or conventional (adopted by agreement).

2.3.2 natural zero of a scale
ru естественный нуль шкалы
de Natürliche Skalanull
fr naturel zéro d′ une échelle

Zero of a scale that represents infinitesimal (null) quantitative realization of measured property.

2.3.3 conventional zero of a scale
ru условный нуль шкалы
de Verabredete Skalanull
fr conventionnel zéro d′ une échelle

Zero of scale of differences (intervals) or scale of an order, that represents by agreement null value of measured property (quantity).
Note
The scale can be defined on both sides from conventional zero. For example, in contemporary calendar scale the event of the Birth of Jesus Christ is taken as a conventional zero. So to date some event we usually say “in ... A.D. (anno Domini)” or “in ... B.C. (before Christ)”.

2.3.4 point of a scale
ru точка шкалы
de Skalapunkt
fr point d′ une échelle

One separate number or sign (designation) from specification for scale of measurements.

2.3.5 class of equivalence
ru класс эквивалентности
de Äquivalenzklasse
fr classe d' équivalence

Subset of realizations of measured property that are conventionally adopted as indistinguishable in the scale of measurements of this property.

2.3.6 range of a scale of measurements
ru диапазон шкалы измерений
de Bereich von Skala der messungen
fr étendue d′ une échelle des mesurages

Limits of variation in measured property that are covered by the specific given scale representation.

2.3.7 unit of measurement [of quantity]
ru единица измерений [величины]
de Einheit [von Größe]
fr unité de mesure [grandeur]

Fixed quantity magnitude that was conventionally defined as correspondent to numeric value of one in the specific scale of measurements.

Notes

1 The term “unit of quantity” is equivalent to the term “unit of measurement”.

2 The term “unit of a physical quantity” describes narrower concept. It is not recommended for use because it is impossible to define the limits of its application. In [2, 3], the adjective "physical" is not used in connection with the concept of "quantity".

3 The term “unit of measurement” has no sense for properties that are described by scales of denominations and scales of an order.

4 Magnitude of units of quantity described by absolute scales are unambiguously defined by dimensionless character of measured quantities.

5 Multiple prefixes of binary units (for example, bits) have special designations (see [4, 6]).

2.3.8 logarithmic unit of measurement
ru логарифмическая единица измерений
de Logarithmen Einheit
fr unité logarithmique de mesure

Unit of measurement of logarithmic scale.

Note

The following logarithmic units of measurement are commonly used: bel, decibel, log, decilog, neper etc.

2.4 Measurement of properties

2.4.1 object of measurement
ru объект измерений
de Objekt der messung
fr object de mesure

Object of activity (body, substance, material, phenomenon, process) one or several specific realizations of quantitative or qualitative properties of which are to be measured.

Note
Not only physical but also non-physical objects can be objects of measurement.

2.4.2 measurable property
ru измеряемое свойство
de Meßbare Eigenschaft
fr propriete de mesure

Common property of objects of measurement which is selected for investigation by measurement.
Note
Not only physical but also non-physical (biological, psychological, social, economical etc.) objects can have quantitative and qualitative measurable properties.

2.4.3 measurable quantity
ru измеряемая величина
de Meßbare Größe
fr grandeur de mesure

Measurable property that is characterized by quantitative differences.
Note
The term “quantity” cannot be applied to qualitative properties which are described by scales of denominations. So the term “property” is wider than the term “quantity”.

2.4.4 measurement
ru измерение
de Messung
fr mesurage

Comparison of concrete realization of measurable property (measurable quantity) with the scale (or its part) of measurements for this property (quantity) in order to obtain the result of measurement (evaluation of a property or value of a quantity).

2.4.5 uniformity of measurements
ru единство измерений
de Einheitlichkeit der Messungen
fr uniformite des mesurages

State of measurements when the results of measurements are expressed in legal units of measurements (of quantities) or in legal scales of measurements and the uncertainties or margins of errors of results are estimated.
Note
This definition of the term “uniformity of measurements” extends it and covers all types of scales including scales of denominations and scales of an order (see 2.1.1).

2.4.6 value of a quantity
ru значение величины
de Größenwert
fr valeur d′ une grandeur

Expression of quantity magnitude according to appropriate scale in the form of some number of accepted units, numbers, marks or other signs (designations).
Note

”Evaluation of a property” may be the analog of the term “value of a quantity” for qualitative properties.

2.4.7 reference quantity value
ru опорное значение величины
de Mengenbezugswert
fr valeur de référence

The value of a quantity that is used as a basis for comparison with the values of quantities of the same kind.
Notes
1 The reference quantity value may be the true value of the quantity to be measured, in which case it is unknown, or the accepted value of the quantity, in which case it is known [2, 3].
2 The reference value of a quantity with its uncertainty is usually given for:
- material, for example, a certified standard sample;
- devices, for example, a stabilized laser;
- reference measurement procedure;
- the results of the comparison of standards.
3 For qualitative measurable properties, you can use a similar concept — the reference value of a property.

2.4.7.1 true value of a quantity
ru истинное значение величины
de Wahrer Größenwert
fr valeur vraie d′ une grandeur

The value of a quantity that corresponds to the definition of the measured value, i.e. ideally reflects the position on the corresponding scale of the realization of the quantitative property of a particular object of activity.
Notes
1 For qualitative properties, a similar term is "true property evaluation".
2 The definition of the measured value includes the adoption of a certain model of the measuring object, in which the true value is represented by a certain parameter. There is always a threshold discrepancy between the model and the measurement object, which is the cause of the definitional uncertainty of the measured value [11].
3 When the definitional uncertainty associated with the measured value is considered negligible compared to the other components of the measurement uncertainty, the measured value can be considered as having "essentially the only" true value. This approach is adopted in GUM [11] and in related documents, where the word "true" is considered superfluous.

2.4.7.2 conventional value of a quantity
ru принятое значение (величины)
de Konventioneller Größenwert
fr valeur conventionnelle d′ une grandeur

The value of a quantity that is conventionally assigned to a quantity for a given purpose.
Notes
1 Sometimes the accepted value of a quantity is an estimate of the true value of a quantity.
2 The measurement uncertainty associated with the accepted value is often small enough and can be assumed to be zero for a specific purpose. In this case, the concept of the conventional true value of a quantity is used.

2.4.8 conventional true value of a quantity
ru действительное значение величины
de Konventioneller wahrer Größenwert
fr valeur conventionellement vraie d′ une grandeur

Value of a quantity which is so close to true value that it can be used instead of true value for the specific task.

2.4.9 evaluation of a property
ru оценка свойства
de Abschätzung einer Eigenschaft
fr evaluation dʹ une propriete

Expression of the place of realization of qualitative property of specific object of measurement in appropriate scale of denominations.
Note
In some cases it is acceptable and suitable to use the term “value” instead of “evaluation” for qualitative properties.

2.4.10 true evaluation of a property
ru истинная оценка свойства
de Wahr Abschätzung einer Eigenschaft
fr valeur evaluation dʹ une propriete

Evaluation of a property that could ideally reflect the realization of qualitative property of specific object of measurement in appropriate scale.

2.4.11 conventional evaluation of a property
ru действительная оценка свойства
de Konventionell Abschätzung einer Eigenschaft
fr evaluation conventionellement dʹ une propriete

Evaluation of a property which is so close to true evaluation that it can be used instead of true evaluation for the specific task.

2.4.12 method of measurement
ru метод измерения
de Meßmethode
fr methode de mesure

Technique or totality of techniques which are used to establish the fact of equivalence between concrete realization of measurable property (value) and the element of scale of measurements for this property.

2.4.13 result of measurement
ru результат измерения
de Meßergebnis
fr resultat d´un mesurage

Value of a quantity or evaluation of a property that was obtained by the way of measurement.
Notes
1 Arithmetic mean value of several uniformly precise acts of measurement is taken most often as a result of measurement in scales of differences (intervals), of ratios and absolute scales.
2 In scales of order, the median of the results of a number of repeated measurements can be taken as the measurement result, but the arithmetic mean cannot be taken.
3 A result of measurement in scales of denominations reflects the equivalence of the specific realization of measured property to the point or class of equivalence of appropriate scale.
4 The result of measurement is invalid without information about its uncertainty or error margins.
Therefore, in general, in accordance with VIM 3 [2], the manual [11] and the recommendations [3], the measurement result is a set values of quantity or property estimates on a scale corresponding to the uncertainty of this measurement, along with any other available and significant information.

2.5 Measuring instruments and etalons

2.5.1 measuring instrument

ru средство измерений
de Meßmittel
fr instrument de mesure

Object having normalized metrological characteristics and designed for execution of measurements. Measuring instrument reproduces and/or keeps some part (or point) of the scale.

2.5.2 material measure

ru мера
de Maßverkörperung
fr mesure materialisee

Measuring instrument that keeps and/or reproduces one or more points of the scale of measurements.
Note
This term can be used not only in scales of quantitative properties (material measure of a value) but also in scales of qualitative properties, e.g. material measure of the colour.

2.5.3 measuring device

ru измерительный прибор
de Meßgerät
fr appareil de mesure

Measuring instrument (or a standard) that is designed to obtain the value of measured quantity or the evaluation of measured property in certain range (part) of measurements scale.

2.5.4 measuring transducer

ru измерительный преобразователь
de Meßumformer
fr transducteur de mesure

Measuring instrument (or its part) which function is to get information about measured quantitative or qualitative property and to transform it into the suitable form for future processing, storage, consequent transformation, indication or transmission.

2.5.5 comparator

ru компаратор
de Komparator
fr comparator

Object that is designed to compare realizations of measurable property (quantity).
Note
There exist comparators not only of quantitative properties (values) but of qualitative properties as well, e.g. comparators of the colour.

2.5.6 standard [etalon]

ru эталон
de Normal
fr etalon

Object that is designed and legalized to reproduce and/or store the scale, the part of it or the magnitude of the unit of measurements and to perform a transmission of them to measuring instruments.

Note
The standard, as a basis for comparison, implements a specification of the measurement scale (see 2.1.3) or a semantic definition of a quantity with established values of properties (quantities) and their accuracy indicators (uncertainties, estimates of the limits of reproduction errors).

2.5.7 **etalon of scale**
ru эталон шкалы измерений
de Normal einer Skala
fr etalon d´un échelle

Etalon that reproduces all scale in the whole or some part of it.
Notes
1 An etalon (measurement standard) can reproduce one point of the scale (one fixed value of a quantity or a qualitative property) – see 2.5.8.
2 Etalons of scales of denominations and scales of an order usually must reproduce in the whole all used parts of the scale.

2.5.8 **etalon of a quantity**
ru эталон величины
de Normal einer Größe
fr etalon d´un grandeur

Etalon that reproduces one or
several values of measured quantity (points of the scale).
Notes
1 An etalon (standard) can reproduce one point of the scale (one fixed value of a quantity or a qualitative property) – see 2.5.8.
2 Etalons of scales of denominations and scales of an order usually must reproduce in the whole all used parts of the scale.

2.6 Errors and uncertainties

2.6.1 **error (of measurement)**
ru погрешность (результата) измерени
de Meßabweichung
fr erreur (de mesure)

Deviation of result of measurement from true value of a quantity or from true evaluation of a qualitative property.
Notes
1 In practice estimation of an error is performed by means of replacement of true value of a quantity or true evaluation of a property by conventional true value of a quantity or conventional true evaluation of a property respectively the reference value of a quantity or property (see 2.4.7).
2 Error in two-dimensional and multi-dimensional scales is described by the deviation of the point of the scale that corresponds to the result of measurement from the point of the scale that corresponds to true value (true evaluation) in the model space from the point of the scale corresponding to the reference value in a particular model space.
3 In scales of ratios and absolute scales the term “absolute error” is used to distinguish it from “relative error”.

2.6.2 **relative error**
ru относительная погрешность (измерения)
de Relative Meßabweichung
fr erreur relative

Ratio of an error of measurement to reference value of a quantity.

N o t e s
1 The concept of relative error can be applied to measurements in scales of ratios and absolute scales. It can be applied also to intervals of values in scales of differences (intervals). But it cannot be applied to the values in scales of differences themselves. For example, it is impossible (it has no sense) to show in percents an error of measurement of Celsius temperature or an error of dating of event.
2 The concept of relative error cannot be used in scales of an order and scales of denominations.

2.6.3 errors of scale reproduction
ru погрешность воспроизведения шкалы
de Meßabweichungen einer Skalareproduction
fr erreurs d ′ une reproduction de échelle

The deviation (difference) of the reproduced value of the property (quantity) scale point from its reference value.
N o t e s
Primary standards and primary reference procedures (methods) are recommended to be characterized not by errors, but by estimated uncertainties in reproducing scale points.

2.6.4 errors of scale transmission
Ru погрешность передачи шкалы
de Meßabweichungen einer skalatranslation
fr erreurs d ′une transmission de echelle

The error in the procedure for transmitting the values of the scale points of the property (quantity), including errors in the transmission method and the standard from which the transmission is carried out, as well as random errors of the standard (measuring instrument) to which the scale is transmitted.

2.6.5 uncertainty of measurement
Ru неопределенность (результата) измерений
de Meßunsicherheit
fr incertitude de mesure

Region (section, area) of a scale of measurements, in which evaluation of a property or value of a quantity is supposed to be contained according to possible dispersion of measurement results.
N o t e s
1 In one-dimensional scales of ratios, of intervals and absolute scales the uncertainty is usually characterized by the parameter derived from root mean square deviation: standard uncertainty and expanded uncertainty as described in “Guide to the expression of uncertainty in measurement” [11].
2 In two-dimensional and multi-dimensional scales the region (area) of a scale that characterizes the uncertainty of measurement presents multidimensional (two-dimensional) region in corresponding model space around the point of the scale which represents the result of measurement [8-10].
3 In scales of an order and of denominations the uncertainty of measurement can be described by the spread of distribution but not by standard (or expanded) uncertainty [5, 10].

2.6.6 uncertainty of scale reproduction
ru неопределенность воспроизведения шкалы
de Unsicherheit einer Skalareproduction
fr incertitude d ′ une reproduction de échelle

The uncertainty of the values of a property (quantity) when reproducing scale points is the procedure for implementing the specification of the measurement scale (see 2.1.3) or the semantic definition of a value.

2.6.7 uncertainty of scale transmission
ru неопределенность передачи шкалы
de Unsicherheit einer Skalatranslation
fr incertitude d ′ une transmission de échelle

The uncertainty of reproduction of the transmitted scale points in combination with the uncertainties of the transmission method, as well as the uncertainty caused by the random error of the standard (measuring instrument) to which the scale is transmitted.

Alphabetic index of equivalents of the terms in Russian

Alphabetic index of equivalents of the terms in German

Alphabetic index of the terms in English

Alphabetic index of equivalents of the terms in French

*Appendix **A***
(for reference)

Elements of the theory of scales of measurements

The term “scale” in metrology practice has at least two different meanings. Firstly the scale, or to be more precise the scale of measurements, is an abstract concept that is defined in present Recommendation. Secondly the scale is readout device of analog measuring instruments. In this Recommendation the term “scale” is used in the first meaning only.

This appendix describes basic elements of the theory of scales of measurements which are necessary to understand and to use them, along with some examples of scales which are widely used in practice.

There are various properties of objects, substances, phenomena, processes that are measured. Measured properties are named as mass, time interval, thermodynamic temperature, hardness, colour etc. Some properties are realized quantitatively (length, mass, temperature etc.) but the others are realized qualitatively. Often, the properties of measurement objects are logically determined by a set of quantitative and (or) qualitative properties, i.e. they are combined multidimensional properties. For example, color is not a scalar quantity, since an expression like "red is greater (less) than blue" does not make sense, it is determined by three-dimensional models [12]. Measured quantitative properties are called measured values. The variety (quantitative or qualitative) of realizations of any property produces the set. This set can be represented by set of numbers or in general case by system of conventional notations thus representing the scale of measurements for this property. Examples of systems of notations are: set of colours denominations (names), unity of classification symbols or concepts, set of marks (points) for evaluation of object state, set of real numbers etc. Elements of the set of property realizations are bound by certain logical relations. Relations of this kind can be “equivalence” (equality), “difference”, “similarity” (closeness) between two elements, their quantitative distinguishability (“more”, “less”), real feasibility of summing, subtraction, multiplication, division operations on elements of the set etc. These particular features of properties define the type of corresponding scales of measurements.

According to logical structure of properties realizations there are five basic types of scales of measurements in the measurements theory distinguished: scales of denominations, scales of an order, scales of differences (intervals), scales of ratios and absolute scales [1-3, 5, 10]. Scales of each type have certain characteristics, main of them are examined below.

Scales of denominations reflect qualitative properties. Their elements are characterized only by relations of equivalence (equality), difference and similarity of particular qualitative realizations of properties. It is impossible to define unit of measurements concept in scales of denominations and consequently a concept of dimension also, zero element is absent in this type of scales. Nevertheless, some statistic operations are possible in processing the results of measurements. For example, it is possible to find modal or the most numerous class of equivalence by the results of measurements.

Examples of scales of denominations

– Scales of colour measurements – colorimetry systems standardized by Commission International d'Eclairage (CIE). In the most widely used standard colorimetry system CIE of the year 1931 the colour is defined by three colour coordinates X, Y, Z in model three-dimensional non-Euclidean space using spectral characteristics of optical emission sources, reflecting and transparent objects and empiric standardized functions of colour addition (see publication 15 CIE [12]).

– Geodesic scales for description of location on the Earth in prescribed coordinate systems (geodesic coordinates, astronomic coordinates, geocentric coordinates, flat rectangular geodesic coordinates and others).

The initial international terrestrial coordinate system is defined by Resolution 9 (24th GCMW, 2011) [4], according to which the International Terrestrial Coordinate System ITRS, defined by the International Union of Geodesy and Geophysics IUGG and implemented by the International Earth Rotation and Coordinate Systems Service IERS, is adopted as the only international coordinate system for terrestrial reference systems (coordinate bases) in all metrological annexes (for the full text of Resolution 9 , see Appendix B).

– Scales of space symmetry (scale of crystal symmetry groups etc.).
– Scales of odours.
– Scale of human blood group taking into consideration Rhesus factor etc.

Scales of an order describe the properties, for which not only the relations of equivalence but also the relations of an order by ascending or descending of quantitative property realizations have sense. Very specialized scales of an order are widely used in methods of testing various products.

In this type of scales it is impossible to introduce units of measurements because they are principally non-linear, i.e. it is logically impossible to establish equality of intervals in different parts of the scale. The results of measurements in these scales are expressed in numbers, marks, points, indexes, levels, but not in units of measurements. Though the results of measurements are often designated by continuous set of real numbers, it is impossible to imply proportionality of these values (because it is logically impossible to define how much times one property realization is more or less than the other). The results of measurements in marks, points, levels are expressed in discrete natural numbers. Scales of an order allow monotone transformations and sometimes zero can exist.

Examples of scales of an order [5, 10]
– Scales of material hardness: for metals (international scales of Brinell, Rockwell, Vickers, Shore), minerals, rubber, plastics etc.
– Scales of intensity and levels for earthquakes.
– Scales of strength of wind and marine surface state (Beaufort number etc.).
– Scales of whiteness for different objects (materials, stuff, goods), e.g. for the paper, wood, flour etc.
– Scales of numbers for photosensitivity of light-sensitive materials.
– Scales of loudness, levels of loudness.
– Scales of aroma strength and taste of water.
– Scales of octane and cetane numbers for petrol.
– Scale of falling number for cereals.
– Scale of evaluation the events at nuclear power plants.
– Scales of acid, iodine, bromine, permanganate, copper, chlorine, bentonite, formolite, peroxide, carbonyl, essential and other numbers for different materials or products.

Scales of differences (intervals) differ from scales of an order by the fact that for properties described by them not only the relations of equivalence and order have sense, but also equality and proportionality of intervals (differences) between different quantitative realizations of the property. It means that the intervals can be summed or multiplied by some coefficient but the values cannot be summed or multiplied because these operations have no sense. There is a typical illustration – scale of time intervals. Time intervals (e.g. periods of work, periods of education) can be summed, it is possible to say that someone is twice older than the other, but it has no sense to sum the dates of two events. Another example is the scale of length (distance) or in other words scale of space extension intervals which is defined by counting out from particularly chosen point in space (conventional zero) to the other point. Practical scales of temperature (Celsius, Fahrenheit, Reaumur) with conventional zero are also scales of this type. Scales of differences have conventional units of measurements and conventional zero based on some reference points. Linear transformations are permitted in scales of differences, and it is possible to calculate average of a distribution, standard deviation and other statistics parameters.

Examples of scales of differences [4, 10]

– International scale of uniform atomic time TAI (Temps Atomique International), in which the magnitude of unit conforms to the definition of the second in International System of Units SI [4].

– Universal Time scale UT0, in which the duration of second is equal to mean solar second [4].

– Universal Time scale UT1 that differs from UT0 by correction for the effect of polar motion. [4].

– Universal Time scale UT2, that differs from UT1 by filtering out periodic seasonal variations of the Earth's rotation [4].

– Coordinated Universal Time scale UTC, in which the value of second is the same as in TAI, but the reference moment can vary in steps of one second in order to keep UTC within 0,9 seconds from UT1 [4].

Note: The current definitions of time scales are given in Resolution 2 of the 26th meeting of the CGPM (its contents are reflected in Appendix 2 SI Brochure 9e édition 2019 [4]). The translation of the resolutions into Russian is published on the COOMET website: http://coomet.org/DB/isapi/cmt_docs/2019/01/26th-CGPM-Resolutions%202018.pdf).

– Calendars (Gregorian, Julian, Moslem, lunar, etc.) [10].

– Celsius temperature scale, in which the unit of measurements (centigrade degree) is equal to Kelvin and thermodynamic temperature 273,16 K is accepted as conventional zero [4].

– Scale of oxidizing potentials of water solutions.

Scales of ratios. In these scales relations of equivalence, order and proportionality exist between different quantitative realizations of a property, also operations of subtraction, multiplication by factor and division can be applied (scales of ratios of the 1st type – proportional). In many cases different realizations of a property can be summed (scales of ratios of the 2nd type – additive).

Conventional units and natural zeroes exist in scales of ratios, scaling transformations are permitted. These scales are widely used in science and technology, it is possible to calculate average of a distribution, standard deviation, standard and expanded uncertainty and other statistics parameters.

Examples of scales of ratios

– Scale of a mass (additive).

– Scale of frequencies, in which the magnitude of unit conforms to the definition of Hertz in SI.

– Scale of thermodynamic temperature (proportional), in which the magnitude of unit conforms to the definition of Kelvin in SI (the International Temperature Scale ITS-90 is maximally close to it and defines a set of reference points).

– Scale of luminous intensity, in which the value of unit conforms to the definition of candela in SI with application of standardized by Commission International d'Eclairage (CIE) [13] *empiric function of spectral luminous efficiency of monochrome radiation on daylight vision for different by spectrum optical radiations. This scale is a source for scales of all photometric quantities.*

– Scales of doses (absorbed, equivalent) and dose rates of ionizing radiations.

– Practical Salinity Scale (PSS-78) [14].

– International Sugar Scale [15].

– Scales of water hardness.

Absolute scales have all features of scales of ratios, but additionally there exists natural unambiguous definition for unit of measurement in them. These scales are used for measurements of relative quantities (ratios of similar quantities): amplification and attenuation coefficients, efficiency factor, reflection and absorption coefficients, amplitude modulation factor, etc.

Examples of absolute scales [5, 10]

– Scales of plane angles with units of measurements according to SI – radian and angular degree.

– Scale of solid angles with unit of measurements according to SI - steradian.

– Scales of coefficients and factors: of amplitude modulation, of nonlinear distortion, of amplification, of attenuation, of reflection.

– Scale for Q-factor of oscillating systems.

– Scale of relative dielectric constant.

– Scales of brilliance.

– Scales of frequency intervals used in acoustic measurements.

– Scales of humidity.

Most of properties are described by one-dimensional scales, but there exist properties described by multidimensional and combined scales: three-dimensional scales of coloures in colorimetry, two-dimensional scales of electric impedances, navigation and geodetic scales of directions (angles) of orientation in space, multidimensional scale of Earth rotation parameters, in which rotation axis position in the Earth’s body, the direction of rotation axis in cosmic space, the value and variations of angular velocity of the Earth’s rotation are defined. Main characteristics and specific features of scales main types are systemized in Table A.1

T a b l e A.1 – Characteristics and specific features of scales main types

Feature	Type of measurement scale					
	Of denomi-nations	Of an order	Of differences (intervals)	Of ratios		Absolute
				1st type	2nd type	
Allowed logical and mathematica relations betweer realizations of properties	Equivalence, distinction	Equivalence, distinction, order	Equivalence, orde intervals can be summed	Equivalence, order, proportionality	Equivalence, order, quantities can be summed	Equivalence, order, proportionality, sometimes quantities can be summed
Zero	Has no sense	Not necessary	Conventional	Defined naturally		
Unit of measurements	Has no sense		Magnitude is defined conventionally			Magnitude is defined by natural criterion
Allowed transformations	Isomorphic mapping	Monotone ansformations	Linear transformations	Multiplication by coefficient		Absent

Practical realization of measurement scales is achieved by the way of standardization of scales and units of measurement as well as methods and conditions (specifications) for their unambiguous reproduction if needed. Scales of denominations and of an order can be realized also without any specialized technical standard devices (Linnaeus classification scale, scale of odours, Beaufort scale) but if it is necessary to build etalons, than they reproduce all practically used part (region) of the scale (e.g. hardness etalon). Any changes in specification that defines scale of denominations or of an order means in practice introduction of a new scale. Scales of differences and of ratios (metric scales) corresponding to the SI are reproduced by etalons as a rule. Etalons for these scales of measurements can reproduce only one point of the scale (mass etalon), some region of the scale (length etalon) or practically full scale (time etalon).

Normative documents in metrology usually consider establishment and reproduction of measurement units only. In practice even for quantities that correspond to basic units in the SI (second, Kelvin, candela etc.) etalons keep and reproduce scales in addition to units (scales of atomic and astronomical time, temperature scale ITS-90 etc.) [4]. In any variant of etalon construction the tracebility chain makes provision for reproduction of all practically needed parts (regions) of scales. Absolute scales can rely on etalons which reproduce any region of them (like etalons of metric scales), but also can be reproduced without etalons (efficiency factor, amplification coefficient). Specific features of scales reproduction (realization) are systemized in Table A.2.

T a b l e A.2 – Specific features of scales realization

Feature	Type of measurement scale				
	Of denominations	Of an order	Of differences (intervals)	Of ratios	Absolute
Establishment of measurements units	Impossible to establish units of measurement in principle.		Possible to establish units of measurement		
Necessity of the standard for scale reproduction	Scales can be reproduced without special technical standard device		Most of scales can be reproduced only by means of special technical standard device		Scales can be reproduced without standards
Standard (if exists) must reproduce	All practically used regions of the scale		Some part or point of the scale and conventional zero	Some part or point of the scale	Obligatory requirements are absent

Scales of ratios, absolute scales and intervals in scales of differences can be subject to logarithmic transformation that leads to change in the type of a scale. These scales are called logarithmic. Logarithmic scales based on application of common and natural logarithms systems and binary logarithms as well are widely used.

Operation of taking a logarithm can be applied to dimensionless quantities only, so before taking a logarithm dimensional quantity must be transformed into dimensionless by its division by conventionally adopted fixed (reference) value of the same quantity, than a logarithm of obtained dimensionless quantity can be calculated.

Depending on the type of scale that was a subject to logarithmic transformation logarithmic scales can be one of two types. Logarithmic transformation of an absolute scale results in absolute logarithmic scale also called logarithmic scale with floating zero, because reference value is not fixed in them. Examples of these scales are scales of signal amplification (attenuation) in decibels. Operations of summing and subtraction are permitted on values of quantities in absolute logarithmic scales.

Logarithmic transformation of scales of ratios and of intervals in scales of differences results in logarithmic scales of intervals with fixed zero corresponding to reference value of initial quantity. Most frequently used reference values are 1 mW, 1 V, 1 μV in radiotechnics, 20 μPa in acoustics etc. In general case no one arithmetic operation can be applied to values in these scales. Quantities expressed in values in these scales can be added or subtracted by means of obtaining their antilogarithms, performing necessary operation and taking the logarithm of the result.

Examples of logarithmic scales [5, 10]

*– Scales of sound pressure level **A**, **B**, **C** and D standardized internationally. Sound pressure level in these scales is conventionally expressed in logarithmic scales (in decibels relative to reference value 2·10-5 Pa).*

– Scales of measurements for irritant action of noise (for noisiness and for perceived noise levels) standardized internationally.

– Audiometric scales (for measurement of hearing acuity and grades of hearing loss).

– Psophometric scales (for measurement of noise interference in communication lines).

*– Scale of hydrogen ion exponent **pH** of water solutions which is reproduced with the use of set of reference solutions.*

– Scales of ionometric exponents.

In practical metrology there is a variety of scales which describe the reactions (responses) of biological objects (a human, first of all) on actuating physical factor. They include luminous measurements and colorimetric scales, scales of sounds perception, scales of equivalent doses of ionizing radiation etc. These scales are commonly named as biophysical scales.

Biophysical scale is a scale of measurements for properties of physical factor (stimulus) modified in such a way that the result of measurement of this property can be used to predict the level or the character of biological object's response on the influence of that factor. These scales are resulting from application of a model that modifies (transforms) the measurement results of stimulus property so that univocal correspondence can be reached between the results of measurement and the characteristics of biological reaction (homomorphic image of the set of stimuli on the set of responses). At the same time equivalent responses can correspond to some subset of stimuli. This modified scale of stimuli by its logical structure approaches to the structure of responses scale thus acquiring some prognostic meaning. Nevertheless, as a rule, biophysical scale of stimuli and a scale of correspondent responses are of different types, so logical relations in the scale of stimuli cannot be simply extended onto prognostic judgments about responses. For example, the scale of brightness from the point of view of stimuli is unlimited additive scale of ratios, but from the point of view of human being response it is a scale of an order in a bounded below and above diapason of stimulus value [10, 13].

Appendix B
(for reference)

Resolution 9, 24th meeting CGPM, 2011 г.
(https://www.bipm.org/documents/20126/30876806/CGPM24.pdf/7c41c2c1-71db-5ef9-4cdd-387279251bac)

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• On the adoption of a common terrestrial reference system

Resolution 9

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

• that a significant number of global navigation satellite systems (GNSS) now exist and that in the future there may be more,

• the proliferation of time and geodesy reference systems in use in these navigation systems, which creates ambiguities for users with regard to the interpretation of navigation and timing solutions, and which renders interoperability between the systems more difficult,

• the existence of the International Terrestrial Reference System (ITRS),

• that the adoption of a common reference system would lead to benefits for users regarding unification of navigation and timing solutions and systems interoperability,

recommends that the ITRS, as defined by the International Union of Geodesy and Geophysics (IUGG) and realized by the International Earth Rotation and Reference Systems Service (IERS), be adopted as the unique international reference system for terrestrial reference frames for all metrological applications.

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