Metrology – in short

2nd edition
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The main purpose of “Metrology – in short©” 2nd edition is to increase the awareness of metrology and to establish a common metrological frame of reference. It is meant to provide users of metrology with a transparent and handy tool to obtain basic metrological information.

Today’s global economy depends on reliable measurements and tests, which are trusted and accepted internationally. They should not create technical barriers to trade. Precondition for this is a widely utilised, sound metrological infrastructure.

The content of the handbook is a description of scientific, industrial and legal metrology. The technical subject fields of metrology and metrological units are described. The international metrology infrastructure is detailed, including the regional metrology organisations such as EUROMET. A list of metrological terms is collected primarily from internationally recognised standards. References are given to institutions, organisations and laboratories by reference to their homepages.

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1. Introduction

1.1 Mankind measures

The death penalty faced those who forgot or neglected their duty to calibrate the standard unit of length at each full moon. Such was the peril courted by the royal site architects responsible for building the temples and pyramids of the Pharaohs in ancient Egypt, 3000 years BC. The first royal cubit was defined as the length of the forearm from elbow to tip of the extended middle finger of the ruling Pharaoh, plus the width of his hand. The original measurement was transferred to and copied into black granite. The workers at the building sites were given copies in granite or wood and it was the responsibility of the architects to maintain them.

Even though we feel ourselves to be a long way from this starting point, both in distance and in time, people have placed great emphasis on correct measurements ever since. Closer to our time, in 1799 in Paris, the first International Metric System was established with the deposition of two platinum standards representing the metre and the kilogram - the forerunner of the present International System of Units - the SI system.

In the Europe of today we measure and weigh at a cost equivalent to more than 1% of our combined GDP with an economic return equivalent to 2-7% of GDP [4], so metrology has become a natural and vital part of our economy. Just for fun, try holding a conversation without using words that refer to weights or measures.

Then there are commerce, trade and regulation that are just as dependent on weights and measures. The pilot carefully observes his altitude, course, fuel consumption and speed, the food inspectorate measures bacteria content, maritime authorities measure buoyancy, companies purchase raw materials by weights and measures, and specify their products using the same units. Processors are regulated and alarms are set off because of measurements. Systematic measurement with known degrees of uncertainty is one of the foundations of industrial quality control and, generally speaking, in most modern industries the costs build up in taking measurements constitute 10-15% of production costs.
Finally, science is completely dependent on measurement. Geologists measure shock waves when the gigantic forces behind earthquakes make themselves felt, astronomers patiently measure the dim light from distant stars in order to determine their age, elementary particle physicists wave their hands in the air when by making measurements in millionths of a second they are able at last to confirm the presence of an almost infinitely small particle. The availability of measuring equipment and the ability to use it is essential for scientists to objectively document the results they achieve. The science of measurement – metrology – is probably the oldest science in the world and knowledge of how it is applied is a fundamental necessity in practically all science-based professions.

Measurement requires common knowledge

Metrology presents a seemingly calm surface covering depths of knowledge that are familiar only to a few, but of use to many - confident that they are sharing a common perception of what is meant by expressions such as metre, kilogram, litre, watt, etc. Confidence is vital in enabling metrology to link human activities together across geographic and professional boundaries. This confidence becomes enhanced with the increased use of network co-operation, common units of measurement and common measuring procedures, as well as the recognition, accreditation and mutual testing of measuring standards and laboratories in different countries. mankind has thousands of years of experience confirming that life really does become easier when people co-operate on metrology.

Metrology is the science of measurement

Metrology covers three main activities:
1. The definition of internationally accepted units of measurement, e.g. the metre.
2. The realisation of units of measurement by scientific methods, e.g. the realisation of a metre through the use of lasers.
3. The establishment of traceability chains by determining and documenting the value and accuracy of a measurement and disseminating that knowledge, e.g. the documented relationship between the micrometer screw in a precision engineering workshop and a primary laboratory for optical length metrology.

Metrology develops ...

Metrology is essential in scientific research, and scientific research forms the basis of the development of metrology itself. Science pushes forward the frontiers of the possible all the time and fundamental metrology follows the metrological aspects of these new discoveries. This means ever better metrological tools enabling researchers to continue their discoveries – and only those fields of metrology that do develop can continue to be a partner for industry and research.

Correspondingly, industrial and legal metrology must also develop in order to keep pace with the needs of industry and society - and remain relevant and useful.

It is the intention to continuously develop "Metrology – in short". The best way of developing a tool is of course to collect the experience of those who use it and the publishers would therefore be grateful for comments, be they criticism or praise. Mail to either of the authors will be appreciated.

1.2 Categories of metrology

Metrology is considered in three categories with different levels of complexity and accuracy:

1. Scientific metrology deals with the organisation and development of measurement standards and with their maintenance (highest level).
2. Industrial metrology has to ensure the adequate functioning of measurement instruments used in industry as well as in production and testing processes.
3. Legal metrology is concerned with measurements where these influence the transparency of economic transactions, health and safety.

Fundamental metrology has no international definition, but it signifies the highest level of accuracy within a given field. Fundamental metrology may therefore be described as the top level branch of scientific metrology.
2. Metrology

2.1 Industrial and scientific metrology

Industrial and scientific metrology are two of the three categories of metrology described in chapter 1.2.

Metrological activities, testing and measurements are valuable inputs to ensuring the quality of many industrial activities. This includes the need for traceability, which is becoming just as important as measurement itself. Recognition of metrological competence at each level of the traceability chain can be established by mutual recognition agreements or arrangements, for example the CIPM MRA and ILAC MRA, and through accreditation and peer review.

2.1.1 Subject fields

Scientific metrology is divided into 9 technical subject fields by BIPM: mass, electricity, length, time and frequency, thermometry, ionising radiation & radioactivity, photometry and radiometry, acoustics and amount of substance. Within EURONET there are two additional subject fields: flow and interdisciplinary metrology.

It is proposed that a number of national editions of the 2nd international edition will be produced.
Table 2.1 Subject fields, subfields and important measurement standards. Only the technical subject fields are included.

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### 2.1.2 Measurement standards

A measurement standard or etalon, is a material measure, measuring instrument, reference material or measuring system intended to define, realise, conserve or reproduce a unit or one or more values of a quantity to serve as a reference.

Example: The metre is defined as the length of the path travelled by light in vacuum during a time interval of 1/299 792 458 of a second. The metre is realised at the primary level in terms of the wavelength from an iodine-stabilised helium-neon laser. On lower-levels, material measures like gauge blocks are used, and traceability is ensured by using optical interferometry to determine the length of the gauge blocks with reference to the above-mentioned laser light wavelength.

The different levels of measurement standards in the traceability chain are shown in figure 2.1. Metrology fields, subfields and important measurement standards are shown in table 2.1 in chapter 2.1.1. An international listing of all measurement standards does not exist.

#### 2.1.3 Certified Reference Materials

A certified reference material (CRM), known as a standard reference material (SRM) in the USA, is a reference material where one or more of its property values are certified by a procedure that establishes traceability to a realisation of the unit, in which the property values are expressed. Each certified value is accompanied by an uncertainty at a stated level of confidence.

CRMs are generally prepared in batches. The property values are determined within stated uncertainty limits by measurements on samples representative of the whole batch.

#### 2.1.4 Traceability & calibration

**Traceability**

A traceability chain, see figure 2.1, is an unbroken chain of comparisons, all having stated uncertainties. This ensures that a measurement result or the value of a standard is related to references at the higher levels, ending at the primary standard.

In chemistry and biology traceability is often established by using CRMs and reference procedures, see chapter 2.1.3 and 2.1.5.
An end user may obtain traceability to the highest international level either directly from a National Metrology Institute or from a secondary calibration laboratory. As a result of various mutual recognition arrangements, traceability may be obtained from laboratories outside the user’s own country.

**Calibration**

A basic tool in ensuring the traceability of a measurement is the calibration of a measuring instrument or reference material. Calibration determines the performance characteristics of an instrument or reference material. It is achieved by means of a direct comparison against measurement standards or certified reference materials. A calibration certificate is issued and, in most cases, a sticker is attached to the calibrated instrument.

Three main reasons for having an instrument calibrated:
1. To ensure readings from the instrument are consistent with other measurements.
2. To determine the accuracy of the instrument readings.
3. To establish the reliability of the instrument i.e. that it can be trusted.

**2.1.5 Reference procedures**

Reference procedures can be defined as procedures of testing, measurement or analysis, thoroughly characterised and proven to be under control, intended for quality assessment of other procedures for comparable tasks, or characterisation of reference materials including reference objects, or determination of reference values.

The uncertainty of the results of a reference procedure must be adequately estimated and appropriate for the intended use.

According to this definition reference procedures can be used to:
- validate other measurement or test procedures, which are used for a similar task, and to determine their uncertainty,
- determine reference values of the properties of materials, which can be compiled in hand books or databases, or reference values which are embodied by a reference material or reference object.

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**Figure 2.1 The traceability chain**

- BIPM (Bureau International des Poids et Mesures)
- National Metrology Institutes or designated national laboratories
- Calibration Laboratories, often accredited
- Reference standards
- Foreign national primary standards
- National primary standards
- Industrial standards
- Measurements

Uncertainty increases down the traceability chain
2.1.6 Uncertainty
Uncertainty is a quantitative measure of the quality of a measurement result, enabling the measurement results to be compared with other results, references, specifications or standards.

All measurements are subject to error, in that the result of a measurement differs from the true value of the measurand. Given time and resources, most sources of measurement error can be identified, and measurement errors can be quantified and corrected for, for instance through calibration. There is, however, seldom time or resources to determine and correct completely for these measurement errors.

Measurement uncertainty can be determined in different ways. A widely used and accepted method, e.g. accepted by the accreditation bodies, is the ISO recommended “GUM-method”, described in “Guide to the expression of uncertainty in measurement” [6]. The main points of the GUM-method and its underlying philosophy are tabulated below.

Example
A measurement result is reported in a certificate in the form

\[ Y = y \pm U \]

where the uncertainty \( U \) is given with no more than two significant digits and \( y \) is correspondingly rounded to the same number of digits, in this example seven digits.

A resistance measured on a resistance meter with a reading of 1,000 052 7 \( \Omega \) where the resistance meter, according to the manufacturer’s specifications, has an uncertainty of 0.081 \( \Omega \), the result stated on the certificate is

\[ R = (1,000 053 \pm 0,000 081) \Omega \]

Coverage factor \( k = 2 \)

The uncertainty quoted in the measurement result is usually an expanded uncertainty, calculated by multiplying the combined standard uncertainty by a numerical coverage factor, often \( k = 2 \) which corresponds to an interval of approximately 95% level of confidence.
2.1.7 Testing

Testing is the determination of the characteristics of a product, a process or a service, according to certain procedures, methodologies or requirements.

The aim of testing may be to check whether a product fulfills specifications (conformity assessment) such as safety requirements or characteristics relevant for commerce and trade.

Testing is:
- carried out widely
- covers a range of fields
- takes place at different levels and
- at different requirements of accuracy.

Testing is carried out by laboratories, which may be first-, second- or third-party laboratories. While first-party laboratories are those of the producer and second-party laboratories are those of the customer, third-party laboratories are independent.

Metrology delivers the basis for the comparability of test results, e.g. by defining the units of measurement and by providing traceability and associated uncertainty of the measurement results.

2.2 Legal metrology

Legal metrology is the third category of metrology, see chapter 1.2. Legal metrology originated from the need to ensure fair trade, specifically in the area of weights and measures. Legal metrology is primarily concerned with measuring instruments which are themselves legally controlled.

The main objective of legal metrology is to ensure citizens of correct measurement results when used:
- in official and commercial transactions
- in labour environments, health and safety.

OIML is the International Organisation of Legal Metrology, see chapter 3.1.7.

There are also many other areas of legislation, outside legal metrology, where measurements are required to assess conformance with regulations e.g. aviation, environmental and pollution control.

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The GUM method

based on the GUM philosophy

1) Identify all important components of measurement uncertainty

There are many sources that can contribute to the measurement uncertainty. Apply a model of the actual measurement process to identify the sources. Use measurement quantities in a mathematical model.

2) Calculate the standard uncertainty of each component of measurement uncertainty

Each component of measurement uncertainty is expressed in terms of the standard uncertainty determined from either a type A or type B evaluation.

3) Calculate the combined uncertainty

The principle:

The combined uncertainty is calculated by combining the individual uncertainty components according to the law of propagation of uncertainty.

In practice:
- For a sum or a difference of components, the combined uncertainty is calculated as the square root of a sum of the squared standard uncertainties of the components.
- For a product or a quotient of components, the same “sum/-difference” rule applies for the relative standard uncertainties of the components.

4) Calculate the expanded uncertainty

Multiply the combined uncertainty by the coverage factor $k$.

5) State the measurement result in the form

$Y = y \pm U$
2.2.1 Legislation for measuring instruments

People using measurement results in the application field of legal metrology are not required to be metrological experts and the government takes responsibility for the credibility of such measurements. Legally controlled instruments should guarantee correct measurement results:
- under working conditions
- throughout the whole period of use
- within given permissible errors.

Therefore requirements are laid down in legislation for measuring instruments and measurement and testing methods including pre-packaged products.

All over the world, national legal requirements for measuring instruments and their use are laid down for the above-mentioned areas.

2.2.2 EU - Legislation for measuring instruments

EU controlled measuring instruments

In Europe, harmonization of legally controlled measuring instruments is currently based on Directive 71/316/EEC, which contains requirements for all categories of measuring instruments, as well as on other directives covering individual categories of measuring instruments and which have been published since 1971. Measuring instruments, which have been granted an EEC type approval and an EEC initial verification, can be placed on the market and used in all member countries without further tests or type approvals.

For historical reasons the scope of legal metrology is not the same in all countries. A new directive, the Measuring Instruments Directive (MID) has been developed and once it comes into force, most of the existing directives related to measuring instruments will be repealed.

EU - Measuring Instruments Directive

The Measuring Instruments Directive aims at the elimination of technical barriers to trade, thus regulating the marketing and usage of the following measuring instruments:

- MI-001 water meters
- MI-002 gas meters
- MI-003 electrical energy meters and measurement transformers
- MI-004 heat meters
- MI-005 measuring systems for liquids other than water
- MI-006 automatic weighing instruments
- MI-007 taximeters
- MI-008 material measures
- MI-009 dimensional measuring systems
- MI-010 exhaust gas analysers

Software used within the instruments is not included in the existing directives but will be covered by the MID.

2.2.3 EU - Enforcement of measuring instrument legislation

Legal control

Preventive measures are taken before marketing of the instruments, i.e. the instruments have to be type-approved and verified. Manufacturers are granted type approval by a competent authorised body once that type of instrument meets all associated legal requirements. With serially manufactured measuring instruments, verification ensures that each instrument fulfils all requirements laid down in the approval procedure.

Market surveillance is a repressive measure to reveal any illegal usage of a measuring instrument. For instruments in use, inspections or periodic re-verifications are prescribed to guarantee that measuring instruments comply with legal requirements. Such legal requirements, including those on usage and validity periods differ from country to country depending on the national legislation. The standards used for such inspections and tests must be traceable to national or international standards.

Consumer protection may differ in various member states and hence the requirements governing the use of instruments become the subject of national legislation. Member states may lay down legal requirements for measuring instruments which are not listed in the MID.

The conformity assessment procedures correspond to those in Directive 93/65/EEC on the modules to be used in all technical harmonisation directives.
2.2.4 Enforcement responsibilities

Directives define:
- The producer's responsibility:
  The product must comply with the requirements in the directives.
- The government's responsibility:
  Non-conforming products must not be placed on the market or put into use.

The producer's responsibility

After the MID is implemented the manufacturer is responsible for affixing the CE-marking and the supplementary metrology marking on the product. By doing so, the manufacturer ensures and declares that the product is in conformity with the requirements of the directives. The Measuring Instruments Directive is a mandatory directive.

The producer of pre-packaged products has to submit his production to a quality assurance system and reference tests. A public administration or a notified body may approve the quality assurance system and a public administration or a notified body may perform the reference tests. The Pre-packaging Directive is a non-mandatory directive.

The government’s responsibility

The government is obliged to prevent measuring instruments that are subject to legal metrological control and that do not comply with applicable provisions of the directives, from being placed on the market and/or put into use. For example, the government shall in certain circumstances ensure that a measuring instrument with inappropriately fixed markings is withdrawn from the market.

The government shall ensure, that pre-packaged products, which are marked with an "e" or an inverted epsilon "ε", conform to the requirements of the relevant directives.

Market surveillance

The government fulfils its obligations through market surveillance. To conduct market surveillance the government authorities inspectors to:
- survey the market,
- note any non-conforming products
- inform the owner or producer of the product about the non-conformance
- report to the government about non-conforming products.

2.2.5 Measurement and testing in legislation

The world economy and the quality of our everyday life depend on reliable measurements and tests which are trusted and accepted internationally and which do not form a barrier to trade.

In addition to those regulations requiring legally verified instruments, many regulated areas require measurements and testing to assess compliance, either with the regulations or mandated documentary standards e.g. aviation, car safety testing, environmental and pollution control and the safety of children's toys. Data quality, measurements and testing are an important part of many regulations.

National Metrology Institutes and other organisations provide advice and guidance on measurement issues to the users.

Regulatory guide to best measurement practice

Measurement may be required at any stage during the regulatory process. Good regulations require an appropriate approach to measurement/testing when:
- establishing the rationale for legislation
- writing the regulation and establishing the technical limits
- undertaking market surveillance.

A guide is available, see link to Regulatory guide chapter 6, developed by a collaboration of European NMIs to assist those considering measurement issues in the regulatory process. The brief condensed extract below gives an indication of the contents of the guide.

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3. Metrological organisation

3.1 International infrastructure

3.1.1 The Metre Convention

In the middle of the 19th century the need for a universal decimal metric system became very apparent, particularly during the first universal exhibitions. In 1875, a diplomatic conference on the metre took place in Paris where 17 governments signed a treaty “the Metre Convention”. The signatories decided to create and finance a permanent, scientific institute: The “Bureau International des Poids et Mesures” (BIPM).

The “Conférence Générale des Poids et Mesures” (CGPM) discusses and examines the work performed by National Metrology Institutes and the BIPM, and makes recommendations on new fundamental metrological determinations and all major issues of concern to the BIPM.

In 2003, 51 states were members of the Metre Convention and a further 10 states were associates of the CGPM.

A number of Joint Committees of the BIPM and other international organisations have been created for particular tasks:

- JCDCMAS Joint Committee on coordination of assistance to Developing Countries in Metrology, Accreditation and Standardization.
- JCGM Joint Committee for Guides in Metrology.
- JCR Joint Committee of the BIPM and the International Astronomical Union.
- JCRB Joint Committee of the Regional Metrology Organisations and the BIPM.
- JCTLM Joint Committee on Traceability in Laboratory Medicine.

There are at least 8 important measurement topics which may need to be addressed at each stage in addition to those above:

1. Which parameters to be measured?
2. Use of existing metrological infrastructure.
3. Ensuring appropriate measurement traceability – traceable to the SI (where possible) through an unbroken, auditable chain of comparisons.
4. Are appropriate methods and procedures available for all tests and/or calibrations?
5. Technical limits established from risk analysis based on robust data – do the existing data support the rationale, are new or additional data required?
6. Use of existing international standards – supplemented with additional requirements if necessary or the development of new international standards.
7. Measurement uncertainty – how does it compare to the technical limits, what is the impact on the ability to assess compliance?
8. Sampling of data – will it be random or selective, is there a scientific basis for requirements related to frequency, what is the impact of timing, seasonal or geographical variations?
3.1.2 CIPM Mutual Recognition Arrangement

In October 1999, the CIPM Mutual Recognition Arrangement (CIPM MRA) for national measurement standards and for calibration and measurement certificates issued by National Metrology Institutes was signed. By the end of 2003, NMIs of 44 Signatory States of the Metre Convention, 2 International organisations and 13 Associates of CGPM had signed the CIPM MRA.

The objectives of the CIPM MRA are to provide governments and other parties with a secure foundation for wider agreements related to international trade, commerce and regulatory affairs. This is achieved through two mechanisms:

- Part 1, establishing the degree of equivalence of national measurement standards maintained by the participating NMIs.
- Part 2, involving mutual recognition in the calibration and measurement certificates issued by participating NMIs.

Currently, around 90% of world trade in merchandise exports is between CIPM MRA participant nations.

Participants recognise each other’s capabilities based on the following criteria:

1) Credible participation in comparisons identified by the international measurement community as of key significance for particular quantities over specified ranges. At present around 400 key comparisons have been designated and are being carried out by NMIs, of which about 130 have been completed.

2) Credible participation in other comparisons related to specific calibration services or that have some trade and/or economic priority for individual countries or geographical regions, the supplementary comparisons. Presently some 50 supplementary comparisons are being undertaken.

3) Declaration of each participant’s calibration and measurement capabilities (CMCs), which are subject to peer review and are published on BIPM key comparison database.

4) A quality system for calibration services which is recognised to be on the level of international best practice, based on agreed criteria.

The first two of these criteria provide the technical basis for recognition under part 1 of the MRA. Compliance with both criteria 3 and 4 enables recognition under part 2 of the MRA.
Many NMIs undertake internationally recognised research within specific sub-fields and maintain and further develop the unit concerned by maintaining and further developing primary standards. NMIs also participate in comparisons at the highest international level.

3.1.4 Designated national laboratories

Designated laboratories in most countries are nominated by the NMI in accordance with the metrological plan of action for the different subject fields and in accordance with the metrological policy of the country.

Designated laboratories in Europe are given in the EUROMET Directory, see the link in chapter 6.

3.1.5 Accredited laboratories

Accreditation is a third-party recognition of a laboratory’s technical competence, quality system and impartiality.

Public as well as private laboratories can be accredited. Accreditation is voluntary, but a number of international, European and national authorities assure the quality of testing and calibration laboratories within their area of competence by requiring accreditation by an accreditation body. In some countries, for example, accreditation is required for laboratories working in the food sector or for the calibration of weights used in retail stores.

Accreditation is granted on the basis of laboratory assessment and regular surveillance. Accreditation is generally based on regional and international standards, e.g. ISO/IEC 17025 “General requirements for the competence of testing and calibration laboratories”, and technical specifications and guidelines relevant for the individual laboratory.

The intention is that tests and calibrations from accredited laboratories in one member country shall be accepted by the authorities and industry in all other member countries. Therefore, accreditation bodies have internationally and regionally agreed multilateral agreements in order to recognise and promote the equivalence of each other’s systems and of certificates and test reports issued by the organisations accredited.

3.1.6 ILAC

The International Laboratory Accreditation Cooperation ILAC is an international cooperation between the various laboratory accreditation schemes operated throughout the world.
Regional Metrology Organisations
The main elements of the International Recommendations are:
- scope, application and terminology
- metrological requirements
- technical requirements
- methods and equipment for testing and verifying conformity to requirements
- test report format

OIML draft recommendations and documents are developed by technical committees or sub-committees composed of representatives from member countries. Certain international and regional institutions also participate on a consultative basis. Co-operation agreements are established between the OIML and institutions such as ISO and IEC with the objective of avoiding conflicting requirements. Consequently, manufacturers and users of measuring instrument test laboratories may simultaneously use publications of the OIML and those of other institutions.

The OIML Certificate System gives manufacturers the possibility of obtaining an OIML Certificate and a Test Report to indicate that a given instrument type complies with the requirements of the relevant OIML International Recommendations. Certificates are issued by OIML member states who have established one or more Issuing Authorities responsible for processing applications from manufacturers wishing to have their instrument types certified. These certificates are the subject of voluntary acceptance by national metrology services.

3.1.8 IUPAP
The International Union of Pure and Applied Physicists focuses on:
- physical measurements
- pure and applied metrology
- nomenclature and symbols for physical quantities and units
- and encourages work contributing towards improved recommended values of atomic masses and fundamental physical constants and facilitation of their universal adoption.

IUPAP issues the “red book” on “Symbols, Units and Nomenclature in Physics.”

Founded twenty years ago, ILAC was formalised as a cooperation in 1996. In 2000, ILAC members signed the ILAC Mutual Recognition Arrangement, which further enhanced the international acceptance of test data, and the elimination of technical barriers to trade as recommended and in support of the World Trade Organisation Technical Barriers to Trade agreement. ILAC was incorporated in January 2003.

Hence ILAC is the world’s principal international forum for the development of laboratory accreditation practices and procedures. ILAC promotes laboratory accreditation as a trade facilitation tool together with the recognition of competent calibration and test facilities around the globe. As part of its global approach, ILAC also provides advice and assistance to countries that are in the process of developing their own laboratory accreditation systems. These developing countries are able to participate in ILAC as Affiliates, and thus can access the resources of ILAC’s more established members.

3.1.7 OIML
The International Organisation of Legal Metrology (OIML) was established in 1955 on the basis of a convention in order to promote the global harmonisation of legal metrology procedures.

OIML is an intergovernmental treaty organization with 58 member countries, which participate in technical activities, and 51 corresponding member countries that join the OIML as observers.

OIML collaborates with the Metre Convention and BIPM on the international harmonisation of legal metrology. OIML liaises with more than 100 international and regional institutions concerning activities in metrology, standardisation and related fields.

A worldwide technical structure provides members with metrological guidelines for the elaboration of national and regional requirements concerning the manufacture and use of measuring instruments for legal metrology applications. The OIML develops model regulations, and issues international recommendations that provide members with an internationally agreed basis for the establishment of national legislation on various categories of measuring instruments. The technical requirements in the European Measuring Instruments Directive are to a large extent equivalent to the International Recommendations of OIML.
3.2 European Infrastructure

The geographical coverage of the regional metrology organisations RMOs are shown on the
RMO-map on page 32.

3.2.1 Metrology - EUROMET

EUROMET is a collaborative forum on measurement standards, established by a Memorandum of
Understanding in 1987. It originated from the Western European Metrology Club WEMC,
which was initiated by a conference on metrology in Western Europe in 1973. EUROMET is
the Regional Metrology Organisation for Europe under the CIPM MRA, see chapter 3.1.2.

EUROMET is a voluntary collaboration between the national metrology Institutes in the EU,
EFTA and EU Accession States. The European Commission is also a member. Other European
states may apply for membership based on certain published criteria.

In 2003 there were 27 members and 12 corresponding applicants and corresponding NMLs,
some countries are in the process of applying for membership.

EUROMET has the following specific tasks:
- Provision of a framework for collaborative research projects and inter-laboratory
  comparisons between the member national metrology Institutes;
- Co-ordination of major investments for metrological facilities;
- Transfer of expertise in the field of primary or national standards between the members;
- Provision of information on resources and services; and co-operation with the
calibration services and legal metrology services in Europe.

3.2.2 Accreditation - EA

The European Co-operation for Accreditation EA is the organisation of accreditation bodies in
Europe. In June 2000 EA was established as a legal entity according to Dutch law. The
members of EA are the nationally recognised accreditation bodies of the member countries
or the candidate countries, of the European Union and EFTA.

EA members who have successfully undergone peer evaluation may sign the appropriate
multilateral agreement for
- certification body accreditation
- laboratory accreditation
- inspection body accreditation
under which they recognise and promote the equivalence of each other’s systems and of
certificates and reports issued by bodies accredited.

In 2003 EA had over 30 members and associated members of which 20 accreditation bodies
were signatories to the testing MLA.

The metrology infrastructure in most countries consists of National Metrology Institutes
NMLs, designated national laboratories and accredited laboratories. The trend is for NMLs
and designated laboratories also to seek third-party assessment of their quality systems through
accreditation, certification or peer assessment.

3.2.3 Legal metrology - WELMEC

The European co-operation in legal metrology WELMEC was established by a Memorandum of
Understanding in 1990 signed by 15 member countries of the EU and 3 EFTA countries, in
connection with the preparation and enforcement of the “New Approach” directives. This
name was changed to “European co-operation in legal metrology” in 1995 but remains
synonymous with WELMEC. Since that time WELMEC has accepted associated membership
of countries, which have signed agreements with the European Union. WELMEC members are
the national legal metrology authorities in the EU and EFTA member countries, whilst national
legal metrology authorities in those countries that are in transition to membership of the EU
are associate members. In 2003 there were 30 member countries.

The goals of WELMEC are to
- develop mutual confidence between the legal metrology authorities in Europe
- harmonise legal metrology activities
- foster the exchange of information between all bodies concerned

The WELMEC Committee consists of delegates from the member and associate member states
and observers from EUROMET, the European co-operation for Accreditation EA, the
International Organisation of Legal Metrology IOLM, and other regional organisations with an
interest in legal metrology. The committee meets at least once a year and is supported by 7
working groups. A small Chairman’s Group advises the chairman on strategic matters.

WELMEC advises the European Commission and the Council regarding the development of the
Measuring Instruments Directive.
Working towards the establishment of a robust regional measuring system, SIM is organised in five sub-regions:
- NORAMET for North America
- CARIMET for the Caribbean
- CAMET for Central America
- ANDIMET for the Andean countries
- SURAMET for South America

SIM also covers legal metrology issues in the Americas. The objective of the Legal Metrology Working Group is the harmonisation of legal metrology requirements and activities in the Americas in consideration of OIML Recommendations and Documents.

3.2.5 EURACHEM
EURACHEM, founded in 1989, is a network of organisations from 31 countries in Europe plus the European Commission, with the objective of establishing a system for the international traceability of chemical measurements and the promotion of good quality practices. Most member countries have established national EURACHEM networks.

EURACHEM and EUROMET cooperate with regard to the establishment of designated laboratories, the use of reference materials and traceability to the SI unit amount of substance, the mole. Technical issues are dealt with by the joint MetChem Working Group.

3.2.6 EUROMET
EUROMET is an organisation corresponding to EUROMET with members from central and east European and Asian countries.

3.3 Americas infrastructure

3.3.1 Metrology - SIM
The Inter American Metrology System, SIM for Sistema Interamericano de Metrologia, was formed by agreement among the national metrology organisations of the 34 member nations of the Organization of American States (OAS). SIM is the Regional Metrology Organisation for the Americas under the CIPM MRA, see chapter 3.1.2.

Created to promote international, particularly Inter-American, and regional cooperation in metrology, SIM is committed to the implementation of a global measurement system within the Americas, in which all users can have confidence.

3.4 Asia Pacific Infrastructure

3.4.1 Metrology - APMP
The Asia Pacific Metrology Programme, APMP brings together the national metrology institutes of the region, and is aimed towards developing international recognition of the measurement capabilities of its members. APMP began in 1977 and is the oldest continually operating regional metrological grouping in the world. APMP is the Regional Metrology Organisation for the Asia-Pacific under the CIPM MRA, see chapter 3.1.2.

APMP works closely with BIPM and other Regional Metrology Organisations to establish the global MRA and has an active intercomparison programme geared towards providing its members with access to the BIPM key comparison database, see chapter 3.1.2.
3.5 African infrastructure

SADC

SADC is the Southern African Development Community and 14 countries are signatories to the SADC Treaty. The “Memorandum of Understanding on Cooperation in Standardisation, Quality Assurance, Accreditation and Metrology in the Southern African Development Community”, the SADC SQAM Programme was signed in 2000. This Memorandum of Understanding established the SADC SQAM Programme and its constituent regional structures SADCA, SADCMET, SADCMEL, SADCSTAN and SQAMEG with the goal of removing Technical Barriers to Trade.

3.5.1 Metrology - SADCMET

The SADC Cooperation in Measurement Traceability SADCMET was established in 2000. Presently SADCMET has 14 ordinary Members, the National Metrology Institutes or de facto National Metrology Institutes of the member countries and 4 Associate Members. SADCMET is the Regional Metrology Organisation for Southern Africa under the CIPM MRA, see chapter 3.1.2.

3.5.2 Accreditation - SADCA

The SADC Cooperation in Accreditation SADCA facilitates the creation of a pool of internationally acceptable accredited laboratories and certification bodies for personnel, products and systems, including quality and environmental management systems in the region, and provides Member States with access to accreditation as a tool for the removal of TBTs in both the voluntary and regulatory areas.

3.5.3 Legal metrology - SADCMEL

The SADC Cooperation in Legal Metrology SADCMEL facilitates the harmonisation of the national Legal Metrology regulations of the Member States and between SADC and other regional and international trading blocs. Its ordinary members are the legal metrology authorities in the SADC member states.

Standardisation - SADCSTAN

The SADC Cooperation in Standardisation SADCSTAN promotes the coordination of standardisation activities and services in the region, with the purpose of achieving harmonisation of standards and technical regulations, with the exception of Legal Metrology regulations.
4. Metrological units

The idea behind the metric system - a system of units based on the metre and the kilogram - arose during the French Revolution when two platinum artefact reference standards for the metre and the kilogram were constructed and deposited in the French National Archives in Paris in 1799 - later to be known as the Metre of the Archives and the Kilogram of the Archives. The French Academy of Science was commissioned by the National Assembly to design a new system of units for use throughout the world, and in 1946 the MKSA system (metre, kilogram, second, ampere) was accepted by the Metre Convention countries. In 1954, the MKSA was extended to include the kelvin and candela. The system then assumed the name the International Systems of Units, SI, (Le Système International d’Unités).

The SI system was established in 1960 by the 11th General Conference on Weights and Measures (CGPM):

“The International System of Units, SI, is the coherent system of units adopted and recommended by the CGPM.”

At the 14th CGPM in 1971 the SI was again extended by the addition of the mole as base unit for amount of substance. The SI system is now comprised of seven base units, which together with derived units make up a coherent system of units. In addition, certain other units outside the SI system are accepted for use with SI units.

SI units

table 4.1 SI base units

table 4.2 SI derived units expressed in SI base units

table 4.3 SI derived units with special names and symbols

table 4.4 SI derived units whose names and symbols include SI-derived units with special names and symbols

Units outside SI

table 4.5 Units accepted because they are widely used

table 4.6 Units to be used within specific subject areas

table 4.7 Units to be used within specific subject areas and whose values are experimentally determined
4.1 SI base units

A base unit is a unit of measurement of a base quantity in a given system of quantities [4].

The definition and realisation of each SI base unit becomes modified as metrological research discovers the possibility of achieving a more precise definition and realisation of the unit.

Example:

The 1889 definition of the metre was based upon the international prototype of platinum-iridium placed in Paris.

In 1960 the metre was redefined as 1 650 763,73 wavelengths of a specific spectral line of krypton-86.

By 1983 this definition had become inadequate and it was decided to redefine the metre as the length of the path travelled by light in vacuum during a time interval of 1/299 792 458 of a second, and realised e.g. in the wavelength of radiation from an iodine-stabilised helium-neon laser. These re-definitions have reduced the relative uncertainty from $10^{-7}$ to $10^{-11}$.

Table 4.1 SI base units [2]

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Base unit</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>length</td>
<td>metre</td>
<td>m</td>
</tr>
<tr>
<td>mass</td>
<td>kilogram</td>
<td>kg</td>
</tr>
<tr>
<td>time</td>
<td>second</td>
<td>s</td>
</tr>
<tr>
<td>electric current</td>
<td>ampere</td>
<td>A</td>
</tr>
<tr>
<td>thermodynamic temperature</td>
<td>kelvin</td>
<td>K</td>
</tr>
<tr>
<td>amount of substance</td>
<td>mole</td>
<td>mol</td>
</tr>
<tr>
<td>luminous intensity</td>
<td>candela</td>
<td>cd</td>
</tr>
</tbody>
</table>

Table 4.2 Examples of SI derived units expressed in SI base units [2]

<table>
<thead>
<tr>
<th>Derived quantity</th>
<th>Derived unit</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>area</td>
<td>square metre</td>
<td>m²</td>
</tr>
<tr>
<td>volume</td>
<td>cubic metre</td>
<td>m³</td>
</tr>
<tr>
<td>speed, velocity</td>
<td>metre per second</td>
<td>m/s</td>
</tr>
<tr>
<td>acceleration</td>
<td>metre per second squared</td>
<td>m·s⁻²</td>
</tr>
<tr>
<td>angular velocity</td>
<td>radian per second</td>
<td>rad·s⁻¹</td>
</tr>
<tr>
<td>angular acceleration</td>
<td>radian per second squared</td>
<td>rad·s⁻²</td>
</tr>
<tr>
<td>density</td>
<td>kilogram per cubic metre</td>
<td>kg·m⁻³</td>
</tr>
<tr>
<td>magnetic field intensity</td>
<td>(linear current density)</td>
<td>A·m⁻¹</td>
</tr>
<tr>
<td>current density</td>
<td>ampere per square metre</td>
<td>A·m⁻²</td>
</tr>
<tr>
<td>moment of force</td>
<td>newton metre</td>
<td>N·m</td>
</tr>
<tr>
<td>electric field strength</td>
<td>volt per metre</td>
<td>V·m⁻¹</td>
</tr>
<tr>
<td>permeability</td>
<td>henry per metre</td>
<td>H·m⁻¹</td>
</tr>
<tr>
<td>permittivity</td>
<td>farad per metre</td>
<td>F·m⁻¹</td>
</tr>
<tr>
<td>specific heat capacity</td>
<td>joule per kilogram kelvin</td>
<td>J·kg⁻¹·K⁻¹</td>
</tr>
<tr>
<td>amount-of-substance concentration</td>
<td>mole per cubic metre</td>
<td>mol·m⁻³</td>
</tr>
<tr>
<td>luminance</td>
<td>candela per square metre</td>
<td>cd·m⁻²</td>
</tr>
</tbody>
</table>

SI base unit definitions

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

The **kilogram** is equal to the mass of the international prototype of the kilogram.

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.

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 x 10⁻⁷ newton per metre of length.

The **kelvin** is the fraction 1/273,16 of the thermodynamic temperature of the triple point of water.

The **mole** is the amount of substance of a system that contains as many elementary entities as there are atoms in 0,012 kg of carbon-12.

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

The **candela** is the luminous intensity in a given direction of a source that emits monochromatic radiation of frequency 540 x 10¹² hertz and has a radiant intensity in that direction of 1/683 watts per steradian.
4.2 SI derived units

A derived unit is a unit of measurement of a derived quantity in a given system of quantities [4].

SI-derived units are derived from the SI base units in accordance with the physical connection between the quantities.

Example:

- From the physical connection between the quantity length measured in the unit $m$, and the quantity time measured in the unit $s$, the quantity speed measured in the unit $m/s$ can be derived.

Derived units are expressed in base units by use of the mathematical symbols multiplication and division. Examples are given in Table 4.2.

The CGPM has approved special names and symbols for some derived units, as shown in Table 4.3.

Some base units are used in different quantities, as shown in Table 4.4. A derived unit can often be expressed in different combinations of 1) base units and 2) derived units with special names. In practice there is a preference for special unit names and combinations of units in order to distinguish between different quantities with the same dimension. Therefore a measuring instrument should indicate the unit as well as the quantity being measured by the instrument.

---

### Table 4.3 SI derived units with special names and symbols

<table>
<thead>
<tr>
<th>Derived quantity</th>
<th>SI derived unit</th>
<th>Symbol</th>
<th>In SI units</th>
<th>In SI base units</th>
</tr>
</thead>
<tbody>
<tr>
<td>force</td>
<td>newton</td>
<td>N</td>
<td>m·kg·s⁻¹</td>
<td></td>
</tr>
<tr>
<td>pressure, stress</td>
<td>pascal</td>
<td>Pa</td>
<td>m²·kg⁻¹·s⁻²</td>
<td></td>
</tr>
<tr>
<td>energy, work, quantity of heat</td>
<td>joule</td>
<td>J</td>
<td>m²·kg·s⁻¹</td>
<td></td>
</tr>
<tr>
<td>power, radiant flux</td>
<td>watt</td>
<td>W</td>
<td>m²·kg·s⁻³</td>
<td></td>
</tr>
<tr>
<td>electric charge, quantity of electricity</td>
<td>coulomb</td>
<td>C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>electric potential difference, electromotive force</td>
<td>volt</td>
<td>V</td>
<td>m²·kg·s⁻²·A⁻¹</td>
<td></td>
</tr>
<tr>
<td>electric capacitance</td>
<td>farad</td>
<td>F</td>
<td></td>
<td>m²·kg·s⁻³·A²</td>
</tr>
<tr>
<td>electric resistance</td>
<td>ohm</td>
<td>Ω</td>
<td>m²·kg·s⁻²·A⁻²</td>
<td></td>
</tr>
<tr>
<td>electric conductance</td>
<td>siemens</td>
<td>S</td>
<td></td>
<td>m⁻²·kg⁻¹·s³·A²</td>
</tr>
<tr>
<td>magnetic flux</td>
<td>weber</td>
<td>Wb</td>
<td>m²·kg·s⁻²·A⁻¹</td>
<td></td>
</tr>
<tr>
<td>magnetic induction, magnetic flux density</td>
<td>tesla</td>
<td>T</td>
<td></td>
<td>m²·kg·s⁻³·A⁻²</td>
</tr>
<tr>
<td>inductance</td>
<td>henry</td>
<td>H</td>
<td>m²·A⁻²</td>
<td></td>
</tr>
<tr>
<td>luminous flux</td>
<td>lumen</td>
<td>lm</td>
<td>cd·sr·m⁻²</td>
<td></td>
</tr>
<tr>
<td>illuminance</td>
<td>lux</td>
<td>lx</td>
<td>cd/m²</td>
<td></td>
</tr>
<tr>
<td>activity (of a radionuclide)</td>
<td>becquerel</td>
<td>Bq</td>
<td>s⁻¹</td>
<td></td>
</tr>
<tr>
<td>absorbed dose, kerma, specific energy (unspecified)</td>
<td>gray</td>
<td>Gy</td>
<td>J/kg</td>
<td></td>
</tr>
<tr>
<td>dose equivalent</td>
<td>sievert</td>
<td>Sv</td>
<td></td>
<td>m²·kg⁻¹·s⁻¹</td>
</tr>
<tr>
<td>plane angle</td>
<td>radian</td>
<td>rad</td>
<td></td>
<td>m · m⁻¹ = 1</td>
</tr>
<tr>
<td>solid angle</td>
<td>steradian</td>
<td>sr</td>
<td></td>
<td>m²·m⁻² = 1</td>
</tr>
<tr>
<td>catalytic activity</td>
<td>kat</td>
<td>kat</td>
<td>s⁻¹·mol⁻¹</td>
<td></td>
</tr>
</tbody>
</table>

---
Table 4.5 gives the units outside the SI that are accepted for use together with SI units because they are widely used or because they are used within specific subject areas.

Table 4.6 gives examples of units outside the SI that are accepted for use within specific subject areas.

Table 4.7 gives units outside the SI which are accepted for use within specific subject areas and whose values are experimentally determined.

### 4.3 Units outside the SI

Table 4.5 Units outside SI which are accepted

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Unit</th>
<th>Symbol</th>
<th>Value in SI units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>minute</td>
<td>min</td>
<td>1 min = 60 s</td>
</tr>
<tr>
<td>Hour</td>
<td>h</td>
<td>h</td>
<td>1 h = 60 min = 3600 s</td>
</tr>
<tr>
<td>Day</td>
<td>d</td>
<td>d</td>
<td>1 d = 24 h</td>
</tr>
<tr>
<td>Plane angle</td>
<td>degree</td>
<td>°</td>
<td>1° = (π/180) rad</td>
</tr>
<tr>
<td>Minute</td>
<td>°</td>
<td>°</td>
<td>1° = (π/10800) rad</td>
</tr>
<tr>
<td>Second</td>
<td>°</td>
<td>°</td>
<td>1° = (π/9000) rad</td>
</tr>
<tr>
<td>Pressure in air</td>
<td>bar</td>
<td>bar</td>
<td>1 bar = 10^5 Pa</td>
</tr>
</tbody>
</table>

Table 4.4 Examples of SI derived units whose names and symbols include SI derived units with special names and symbols [2]

<table>
<thead>
<tr>
<th>Derived quantity</th>
<th>Derived unit</th>
<th>Symbol</th>
<th>In SI base units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamic viscosity</td>
<td>pascal second</td>
<td>Pa·s</td>
<td>m·kg·s⁻¹</td>
</tr>
<tr>
<td>Moment of force</td>
<td>newton metre</td>
<td>N·m</td>
<td>m³·kg·s⁻²</td>
</tr>
<tr>
<td>Surface tension</td>
<td>newton per metre</td>
<td>N/m</td>
<td>m⁻¹·kg·s⁻²</td>
</tr>
<tr>
<td>Angular velocity</td>
<td>radian per second</td>
<td>rad/s</td>
<td>m⁻¹·kg·s⁻²</td>
</tr>
<tr>
<td>Angular acceleration</td>
<td>radian per second squared</td>
<td>rad/s²</td>
<td>m⁻²·kg·s⁻²</td>
</tr>
<tr>
<td>Heat flux density</td>
<td>watt per square metre</td>
<td>W/m²</td>
<td>m⁻²·kg·s⁻³</td>
</tr>
<tr>
<td>Heat capacity, entropy</td>
<td>joule per kelvin</td>
<td>J/K</td>
<td>m⁻³·kg·s⁻³·K⁻¹</td>
</tr>
<tr>
<td>Specific heat capacity</td>
<td>joule per kilogram</td>
<td>J/kg</td>
<td>m⁻³·kg⁻¹·s⁻¹·K⁻¹</td>
</tr>
<tr>
<td>Specific energy</td>
<td>joule per kilogram</td>
<td>J/kg</td>
<td>m⁻³·kg⁻¹·s⁻²·K⁻¹</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td>watt per metre kelvin</td>
<td>W/(m·K)</td>
<td>m⁻¹·kg⁻¹·s⁻¹·K⁻¹</td>
</tr>
<tr>
<td>Energy density</td>
<td>joule per cubic metre</td>
<td>J/m³</td>
<td>m⁻¹·kg·s⁻³</td>
</tr>
<tr>
<td>Electric field strength</td>
<td>newton per metre</td>
<td>N/m</td>
<td>m⁻¹·kg·s⁻²</td>
</tr>
<tr>
<td>Electric charge density</td>
<td>coulomb per cubic metre</td>
<td>C/m³</td>
<td>m⁻³·A⁻¹</td>
</tr>
<tr>
<td>Electric flux density</td>
<td>coulomb per square metre</td>
<td>C/m²</td>
<td>m⁻¹·A⁻¹</td>
</tr>
<tr>
<td>Permittivity</td>
<td>farad per metre</td>
<td>F/m</td>
<td>m⁻¹·kg⁻¹·s⁴·A⁻²</td>
</tr>
<tr>
<td>Permeability</td>
<td>h/m</td>
<td>m⁻¹·kg⁻¹·s⁻²·A⁻¹</td>
<td></td>
</tr>
<tr>
<td>Molar energy</td>
<td>joule per mole</td>
<td>J/mol</td>
<td>m⁻³·kg⁻¹·s⁻²·mol⁻¹</td>
</tr>
<tr>
<td>Molar entropy, molar heat capacity</td>
<td>joule per mole kelvin</td>
<td>J/mol·K</td>
<td>m⁻³·kg⁻¹·s⁻²·K⁻¹·mol⁻¹</td>
</tr>
<tr>
<td>Molar expansivity (x and y only)</td>
<td>joule per kilogram</td>
<td>J/kg</td>
<td>m⁻³·kg⁻¹·s⁻²·mol⁻¹</td>
</tr>
<tr>
<td>Absorbed dose rate</td>
<td>gray per second</td>
<td>Gy/s</td>
<td>m⁻¹·kg⁻¹·s⁻¹</td>
</tr>
<tr>
<td>Radiation intensity</td>
<td>watt per steradian</td>
<td>W/ster</td>
<td>m⁻²·kg⁻¹·s⁻³·A⁻¹</td>
</tr>
<tr>
<td>Catalytic (activity) concentration</td>
<td>katal per cubic metre</td>
<td>kat/m³</td>
<td>m⁻³·kg⁻¹·s⁻³·mol⁻¹</td>
</tr>
</tbody>
</table>
4.4 SI prefixes

The CGPM has adopted and recommended a series of prefixes and prefix symbols, shown in table 4.8.

Rules for correct use of prefixes:

1. Prefixes refer strictly to powers of 10 (and e.g. not powers of 2).
   Example: One kilobit represents 1000 bits not 1024 bits

2. Prefixes must be written without space in front of the symbol of the unit.
   Example: Centimetre is written as cm not c m

3. Do not use combined prefixes.
   Example: 10^{-6}kg must be written as 1 mg not 1/1000 kg

4. A prefix must not be written alone.
   Example: 10^{9}/m^{3}must not be written as G/m^{3}

<table>
<thead>
<tr>
<th>Factor</th>
<th>Prefix name</th>
<th>Symbol</th>
<th>Prefix name</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>10^{-10}</td>
<td>decia</td>
<td>da</td>
<td>10^{-1}</td>
<td>deci</td>
</tr>
<tr>
<td>10^{-9}</td>
<td>hecto</td>
<td>h</td>
<td>10^{2}</td>
<td>centi</td>
</tr>
<tr>
<td>10^{-6}</td>
<td>kilo</td>
<td>k</td>
<td>10^{3}</td>
<td>milli</td>
</tr>
<tr>
<td>10^{-3}</td>
<td>mega</td>
<td>M</td>
<td>10^{6}</td>
<td>micro</td>
</tr>
<tr>
<td>10^{-2}</td>
<td>giga</td>
<td>G</td>
<td>10^{9}</td>
<td>nano</td>
</tr>
<tr>
<td>10^{4}</td>
<td>tera</td>
<td>T</td>
<td>10^{12}</td>
<td>pico</td>
</tr>
<tr>
<td>10^{5}</td>
<td>peta</td>
<td>P</td>
<td>10^{15}</td>
<td>femto</td>
</tr>
<tr>
<td>10^{6}</td>
<td>exa</td>
<td>E</td>
<td>10^{18}</td>
<td>atto</td>
</tr>
<tr>
<td>10^{7}</td>
<td>zetta</td>
<td>Z</td>
<td>10^{21}</td>
<td>zepto</td>
</tr>
<tr>
<td>10^{8}</td>
<td>yotta</td>
<td>Y</td>
<td>10^{24}</td>
<td>yocto</td>
</tr>
</tbody>
</table>

Table 4.6 Units outside the SI which are accepted for use within specific subject areas

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Unit</th>
<th>Symbol</th>
<th>Value in SI units</th>
</tr>
</thead>
<tbody>
<tr>
<td>length</td>
<td>mile</td>
<td></td>
<td>1 nautical mile = 1852 m</td>
</tr>
<tr>
<td>speed</td>
<td>knot</td>
<td></td>
<td>1 nautical mile per hour = (1852/3600) m/s</td>
</tr>
<tr>
<td>mass</td>
<td>carat</td>
<td></td>
<td>1 carat = 2 x 10^{-5} kg = 200 mg</td>
</tr>
<tr>
<td>linear density</td>
<td>ton</td>
<td></td>
<td>1 tonne = 10^{3} kg/m = 9 mg/m</td>
</tr>
<tr>
<td>strength of optical systems</td>
<td>dioptre</td>
<td></td>
<td>1 dioptre = 1 m</td>
</tr>
<tr>
<td>pressure in human body fluids</td>
<td>millimetres of mercury</td>
<td>mmHg</td>
<td>1 mmHg = 133 322 Pa</td>
</tr>
<tr>
<td>area</td>
<td>are a</td>
<td></td>
<td>1 a = 100 m²</td>
</tr>
<tr>
<td>pressure</td>
<td>bar</td>
<td></td>
<td>1 bar = 10^{5} Pa</td>
</tr>
<tr>
<td>length</td>
<td>angstrom</td>
<td>Å</td>
<td>1 Å = 0,1 nm = 10^{-10} m</td>
</tr>
<tr>
<td>Cross-section</td>
<td>barn</td>
<td>b</td>
<td>1 b = 10^{-24} m²</td>
</tr>
</tbody>
</table>

Table 4.7 Units outside the SI which are accepted within specific subject areas and whose values are experimentally determined [2]

The combined uncertainty (coverage factor k=1) on the last two digits of the number is given in parentheses.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Unit</th>
<th>Symbol</th>
<th>Definition</th>
<th>In SI units</th>
</tr>
</thead>
<tbody>
<tr>
<td>energy</td>
<td>electronvolt</td>
<td>eV</td>
<td>1 eV is the kinetic energy of an electron passing a potential difference of 1 V in vacuum.</td>
<td>1 eV = 1,602 177 33 (49) · 10^{-19}J</td>
</tr>
<tr>
<td>Mass</td>
<td>atomic mass unit</td>
<td>u</td>
<td>1 u is equal to 1/12 of the mass of a neutral atom of the nuclide ^12C in the ground state.</td>
<td>1 u = 1,660 540 2 (10) · 10^{-27}kg</td>
</tr>
<tr>
<td>length</td>
<td>astronomical unit</td>
<td>ua</td>
<td>1 ua = 1,495 978 706 81 (10) · 10^{15} m</td>
<td></td>
</tr>
</tbody>
</table>
4.5 Writing of SI unit names and symbols

1. Symbols are not capitalised, but the first letter of a symbol is capitalised if:
   1) the name of the unit comes from a person's name or
   2) the symbol is the beginning of a sentence.

   Example: The unit kelvin is written as the symbol K.

2. Symbols must remain unchanged in the plural – no “s” is added.

3. Symbols are never followed by full stops unless at the end of a sentence.

4. Units combined by the multiplication of several units must be written with a raised dot or a space.

   Example: N m or N m

5. Units combined by the division of one unit with another must be written with a slash or a negative exponent.

   Example: m/s or m s⁻¹

6. Combined units must only include one slash.

   The use of parentheses or negative exponents for complex combinations is permitted.

   Example: m·kg/(s²·A) or m kg·s⁻²·A⁻¹ but neither m kg/s/A nor m kg·s⁻²·A⁻¹

7. Symbols must be separated from the numerical value they follow by a space.

   Example: 5 kg not 5 kg

8. Unit symbols and unit names should not be mixed.

Numerical notation

1. A space should be left between groups of 3 digits on either the right or left-hand side of the decimal place (15 739,012 53). In four-digit numbers the space may be omitted. Commas should not be used as thousand separators.

2. Mathematical operations should only be applied to unit symbols (kg/m³) and not unit names (kilogram/cubic metre).

3. It should be clear to which unit symbol a numerical value belongs and which mathematical operation applies to the value of a quantity:

   Examples: 35 cm x 48 cm not 35 x 48 cm 100 g/H11006 2 g not 100/H11006 2 g
5. Vocabulary


Accredited laboratory: Laboratory with 3rd party approval of the laboratory’s technical competence, the quality assurance system in use, and its impartiality. See chapter 3.1.1.

Accuracy class: Measuring instruments that meet certain metrological requirements intended to keep errors within specified limits. [5]

Accuracy of a measuring instrument: The ability of a measuring instrument to give responses close to a true value. [5]

Accuracy of measurement: Agreement between the result of a measurement and a true value of the measured [5].

Adjustment of a measuring instrument: Process that brings a measuring instrument into a functional condition corresponding to the purpose for which it is used. [4]

ANRC: Asia-Pacific Economic Cooperation.

ANQPC: Asia-Pacific Laboratory Accreditation Cooperation, see chapter 2.4.6.

ANQMP: Asia-Pacific Metrology Programme, see chapter 2.1.4.

Artefact: An object fashioned by human hand. Examples of artefacts made for taking measurements are a weight and a measuring rod.

Batch: a (measurement) unit of measurement for a basic magnitude in a given system of magnitudes. [4]

BNM: Bureau National de Métrologie, the national metrological institute of France.

BIPM: Bureau International des Poids et Mesures, see chapter 3.1.1.

BIPM key comparison database, see chapter 3.1.2.

Calibration certificate: Result(s) of a calibration can be registered in a document sometimes called a calibration certificate or a calibration report. [4]

Calibration history: Measuring equipment: Complete registration of the results from the calibrations of a piece of measuring equipment, or measuring artefact, over a long period of time, to enable the evaluation of the long-term stability of the piece of equipment or the measuring artefact.

Calibration interval: Time interval between two consecutive calibrations of a measuring instrument.

Calibration report: Result(s) of a calibration can be registered in a document sometimes called a calibration certificate or a calibration report. [4]

Calibration set: A set of operations that establishes, under specified conditions, the relationship between values of quantities obtained by a measuring instrument or measuring system, or values represented by a material measure or a reference material and the corresponding values realised by standards. [4]


CCEM: Consultative Committee for Electricity and Magnetism. Established 1927.


CCM: Consultative Committee for Cooling Pans, Thermometry, Established 1937.


CCG: Consultative Committee for Mass and Weight. Established 1946.


Metrology is divided into 11 subject fields. See chapter 2.1.1.

A measuring system based on metres and kilograms. Subsequently developed into the SI system.

See Metrology, legal.

Legal metrology of measuring units. In 2003 there were 51 member nations. See chapter 3.1.1.

The national metrological institute of Norway. See chapter 3.1.2.

Justervesenet

Joint Committee of the BIPM, see chapter 3.1.1.

JCRB

Swiss Federal Office of Metrology and Accreditation, the national metrological institute of Switzerland. METAS

The International Union of Pure and Applied Physicists, see chapter 3.1.8. IUPAP

Measuring unit of a system of measurement. [4]

Complete set of measuring instruments and other equipment assembled to carry out specified measurements. [4]

IPQ

Value attributed to a measured measurand arrived at by measurement. [4]

Measuring result

within specified limits. [4]

International (measuring) standard

Set of values of measurands for which the error of a measuring instrument is intended to lie within specified limits. [4]

Error (for a measuring instrument), systematic

Measure of the deviation of a measuring instrument's indication from the true value of a given measurand. [4]

Error (for a measuring instrument), largest permissible

Extreme values for an error permitted by specifications, regulations, etc. for a given measuring instrument. [4]

Error limit (for a measuring instrument)

Extreme values for an error permitted by specifications, regulations, etc. for a given measuring instrument. [4]

Error in a measuring instrument, systematic

Systematic difference between the indication of a measuring instrument and the true value of a measurand. [4]

Influence quantity

Quantity that is not the measurand (quantity subject to measurement) but that affects the result of the measurement. [4]

Instrument constant

Coefficient by which the direct indication of a measuring instrument must be multiplied to give the true value of the measured quantity. [4]

International (measuring) standard

Standard recognised by a national decision to serve in a country as the basis for assigning values to other standards of the quantity concerned. [4]

Measurement standard, national

Set of operations necessary to preserve the metrological characteristics of a measurement standard within appropriate limits. [4]

Maintenance of a measurement standard

Set of operations necessary to preserve the metrological characteristics of a measurement standard within appropriate limits. [4]

Market surveillance

used to refer to legal metrology, see chapter 2.1.4.

Material measure

Device intended to reproduce or supply, in a permanent manner during its use, one or more known values of a given quantity, e.g. a weight, a volume measure, a gauge block, or a reference material. [4]

Maximum permissible error (of a measuring instrument)

Extreme values of an error permitted by specifications, regulations, etc. for a given measuring instrument. [4]

Measuring (material) device

Device intended to take a measurement, alone or in conjunction with supplementary devices. [4]

Measuring procedure

Set of operations, described specifically, used in the performance of particular measurements according to a given method. [4]

Measurement set of operations for the purpose of determining the value of a quantity. [4]

Measurement standard

Standard recognised by an international agreement to serve internationally as the basis for assigning values to other standards of the quantity concerned. [4]

Measurement standard, international

Set of operations necessary to preserve the metrological characteristics of a measurement standard within limits. [4]

Measurement standard, maintenance

Set of operations for the purpose of determining the value of a quantity. [4]

Measure, material

Particular quantity subject to measurement. [4]

Measurand

measurement signal from the input to the output. [4]

International Laboratory Accreditation Coorperation, see chapter 3.1.6. ILAC

Good Laboratory Practice. Accrediting bodies approve laboratories in accordance with the GLP rules of OECD. GLP

International Electrotechnical Commission. IEC

See chapter 2.2.4. e-mark

Market surveillance

values of a given quantity. e.g. a weight, a volume measure, a gauge block, or a reference material. [4]

EOTC

Extreme values of an error permitted by specifications, etc. for a given measuring instrument. [4]

Maximum permissible errors (of a measuring instrument)

Extreme values of an error permitted by specifications, regulations, etc. for a given measuring instrument. [4]
Scale range

The scientific foundation of a method of measurement. See chapter 1.2.

Principle of measurement

Scale division whose value is accepted without reference to other standards of the same quantity. See chapter 2.1.2.

Southern African Development Community (SADC) Cooperation in Measurement Traceability. See chapter 3.5.1.

Standard that is designated or widely acknowledged as having the highest metrological qualities and realised and maintained standards at the highest international level. The input signal for a measuring system can be called a stimulus and the output signal can be called a response. See chapter 2.2.3.

Laboratory that performs internationally adopted fundamental metrological research and which assigns values to other standards of the quantity concerned. A system of measurement units based on Metres, Kilograms, Seconds and Amperes. In 1954 the system was extended to include the Kelvin and the Candela. It was then given the name "SI system." The Measuring Instruments Regulation, the national metrological institute of the Netherlands. The Measuring Instruments Directive, see chapter 2.2.1.

National Physical Laboratory, the national metrological institute of UK. The kilogram prototype (1 kg weight) in Paris is today the only prototype in the SI system.

National Metrology Institute NMI. See chapter 3.1.3. The national metrological institute of Canada. National Research Council, Institute for National Measurement Standards, the national metrological institute of Canada. The kilogram prototype (1 kg weight) in Paris is today the only prototype in the SI system.

Nederlands Meet Instituut - Van Swinden Laboratorium, the national metrological institute of the Netherlands. The kilogram prototype (1 kg weight) in Paris is today the only prototype in the SI system.

Reference material that has the highest metrological qualities and whose value is determined in a given organisation, and from which measurements taken at the locality are derived. See chapter 2.1.2.

Reference values of the highest metrological quality which is accessible at a given location or a given organisation, and from which measurements taken at the locality are derived. See chapter 2.1.2.

Reference values normally part of the reference conditions of an instrument. See also Values, determined.

Relative error of measurement divided by a true value of the measurand. See chapter 2.2.4.

Relative error

Expression that represents a quantity of a system of quantities as the product of powers of factors that represent the basic quantities of the system. See chapter 1.2.

Repeatability (of results of measurements)

Closeness of the agreement between the results of successive measurements. See chapter 2.2.3.

Reproducibility (of results of measurements)

Closeness of agreement between the results of measurements of the same measurand carried out under changed conditions of measurement. See chapter 2.2.3.

Reproducibility of measurement

Closeness of agreement between the results of measurements of the same measurand carried out under repeatability conditions. See chapter 2.2.3.

Result, corrected

Measuring result after correction for systematic error. See chapter 2.1.2.

Result, corrected

Expression that represents a quantity of a system of quantities as the product of powers of factors that represent the basic quantities of the system. See chapter 1.2.

Result, corrected

Measuring result after correction for systematic error. See chapter 2.1.2.

Result, corrected

Expression that represents a quantity of a system of quantities as the product of powers of factors that represent the basic quantities of the system. See chapter 1.2.

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Result, corrected

Measuring result after correction for systematic error. See chapter 2.1.2.

Result, corrected

Expression that represents a quantity of a system of quantities as the product of powers of factors that represent the basic quantities of the system. See chapter 1.2.

Result, corrected

Measuring result after correction for systematic error. See chapter 2.1.2.
Scale spacing Distance between two successive adjacent scale marks measured along the same line as the scale length. [a]

Secondary standard Standard whose value is assigned by comparison with a primary standard of the same quantity. [a]

Sensor Element in a measuring instrument or a measuring chain that is directly influenced by the measurand. [c]

SI system The international system of units, in Systeme Internationale d’Unites, continuing the formal definition of all SI basic units, approved by the General Conference on Weights and Measures. See chapter 4.

SI unit A unit in the SI system. See chapter 4.

SIM Sistema Internetamericano de Metrologia, the Inter-American Metrology System is the regional organization for metrology of the Americas, see chapter 3.3.1.

SIU Svenska Insatser och Forskningsinstitut, the national metrological institute of the Slovak Republic.

Span Modulus of the difference between two limits of a nominal range. [a]

Stability The ability of a measuring instrument to maintain constant its metrological characteristics with time. [c]

Standard deviation, experimental Deviation of a series of measurements of the same measured, characterises the dispersion of the results and is given by the formula for standard deviation. [c]

Standard See Measuring standard.

Standard, compound A set of similar material measures or measuring instruments that, through their combined use, constitute a standard called a compound standard. [a]

Standard, transfer Standard used as an intermediary to compare standards. [a]

Standard Reference Material, see Reference Material, Certified.

Stimulus The input signal for a measuring system can be called a stimulus and the output signal can be called a response. [c]

System of measurement A set of basic units and derived units defined in accordance with given rules for a given system of values. [a]

System of units See System of measurement units.

Systematic error Error that would result from an infinite number of measurements of the same measured carried out under repeatability conditions minus a true value of the measured. [a]

TI Technical Bureau to Trade.

Testing Technical procedure consisting of the determination of one or more characteristics of a given product, process or service, in accordance with a specified procedure. [a]

Threshold, resolution capability (determinability) Limit of change in a stimulus that produces no detectable change in the response of a measuring instrument, the change in the stimulus being slow and monotonically. [a]

Transferability The ability of a chain of comparisons to be transferred from one location to another. [c]

Transferable The description "transferable" equipment should be used when the intermediate link is not a standard. [a]

Transfer standard Standard used as an intermediary to compare standards. [a]

Uncertainty of measurement Imprecision, associated with the result of a measurement that characterises the dispersion of values that could reasonably be attributed to the measured. [a] The estimation of uncertainty in accordance with GUM guidelines is usually accepted. [a]

Uncertainty expanded See chapter 2.1.6.

Unit (of measurement) Particular quantity defined and adopted by convention, with which other quantities of the same kind are compared in order to express their magnitudes relative to that quantity. [a] the chapter 4.

Unit of measurement (derived) Coefficient behind unit of measurement that can be expressed as the product of basic units in powers with the proportionality coefficient 1. [a]

Value (of a measured) Transformed value of a measuring signal that represents a given measurand [a]

Value (of a quantity) Magnitude of a particular quantity generally expressed as a unit of measurement multiplied by a number. [a]

Values, nominal Rounded or approximate value of a characteristic of a measuring instrument that provides a guide to its use. [a]

Values, derived Conditions for use intended to keep the metrological characteristics of a measuring instrument within specified limits. [a]

VIM International Vocabulary of basic and general terms in Metrology. [a]

WELMEC See chapter 3.2.3.

WTO World Trade Organization.
6. Information on metrology – links

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<th>Contact</th>
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<tr>
<td>Accreditation in the Americas</td>
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<td>WELMEC <a href="http://www.welme.org">www.welme.org</a></td>
</tr>
</tbody>
</table>

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<tr>
<th>Source</th>
<th>Contact</th>
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<td>BIPM</td>
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<td>SACMET <a href="http://www.sacmet.org.br">www.sacmet.org.br</a></td>
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<td>SIM <a href="http://www.sim-metrologia.org.br">www.sim-metrologia.org.br</a></td>
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<td>National Metrology Institutes in Asia Pacific</td>
<td>APMP Asian Pacific Metrology Programme</td>
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<tr>
<td>National Metrology Institutes in Europe</td>
<td>EUROMET Directory <a href="http://www.euromet.org">www.euromet.org</a></td>
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<td>Proficiency testing schemes PTS regularly organised in EU</td>
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<td>Reference materials for chemical analysis</td>
<td>INFM COPN database <a href="http://www.infn.it">www.infn.it</a></td>
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<td>Regional Metrology Organisations RMO</td>
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<td>Regulatory guide</td>
<td>APLMF Asian Pacific Legal Metrology Forum <a href="http://www.aplmp.org/index.shtml">www.aplmp.org/index.shtml</a></td>
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<td>Standards</td>
<td>ISO International Organisation for Standardisation</td>
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<td>Technical Barriers to Trade</td>
<td>EC DG Trade Market Access database <a href="http://www.bipm.org">www.bipm.org</a></td>
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<td>SI system</td>
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<td>Symbols, constants etc., in physics</td>
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Source

OIML
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BIPM
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APMP
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INFM
BPM
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IUPAP “Red Book”
7. References

The references are listed by their reference number [x]


