QUALEB
QUALITY PROGRAMME

QUALITY Guide

An ABC Guide on Metrology

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QualityGuide

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An ABC Guide on
Metrology

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Edited by QUALEB, the Quality Programme, hosted at the Ministry of Economy & Trade, Lebanon.
Azarieh Building – Block A 01 - 8th Floor, Downtown Beirut
Tel: +961 1 982357 • Tel / Fax: +961 1 982299 www.qualeb.org

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1 - ACCRONYMS

• BIPM	Bureau International des Poids et Mesures, see chapter 2, page 26
• CEN	Comité Européene de Normalisation. European standardisation organisation
• CGPM	Conférence Générale des Poids et Mesures. Held first time in 1889. Meeting every 4th year - see chapter 2, page 26
• CIPM	Comité Internationale des Poids et Mesures - see chapter 2, page 26
• CMC	Calibration and Measurement Capabilities - see chapter 2 page 26
• COLIBAC	Lebanese Accreditation Council, (Conseil Libanais d'Accreditation) - see chapter 2, page 33
• CRM	See Reference material, certified
• EA	European co-operation for Accreditation
• EPTIS	European Proficiency Testing Information System - link in chapter 5, page 44
• Eurachem	See chapter 2, page 32
• EUROLAB	Voluntary co-operation between testing and calibration laboratories in Europe - see chapter 2, page 31
• EURAMET (EUROMET)	Co-operation between national metrological institutes in Europe, Turkey and the European Commission - see chapter 2, page 30

- GUM — Guide to the Expression of Uncertainty in Measurement
- IEC — International Electrotechnical Commission
- ILAC — International Laboratory Accreditation Co-orperation - see chapter 2, page 29
- IRMM — Institute for Reference Materials and Measurements, Joint Research Centre under the European Commission
- ISO — International Organisation for Standardisation
- MID — The Measuring Instruments Directive
- MRA — Mutual Recognition Arrangement (CIPM, ILAC)
- NMI — National Metrological Institute
- OIML — Organisation Internationale de Métrologie Légale, International Organisation of Legal Metrology
- PTS — Proficiency testing scheme
- RMO — Regional Metrology Organisation
- SI system — The international system of units, Le Système International d'Unité
- VIM — International Vocabulary of basic and general terms in Metrology - see chapter 6, page 44
- WELMEC — The European co-operation in legal metrology - see chapter 2, page 31

1. METROLOGY

Metrology is the science of measurement -
from the Greek word 'metron' = measurement.

Metrology covers three main activities:

- The definition of internationally accepted units of measurement, e.g. the metre
- The realisation of units of measurement by scientific methods e.g. the realisation of a metre through the use of lasers
- 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

1.1 Categories of metrology

Metrology is separated into three categories with different levels of complexity and accuracy:

- Scientific metrology deals with the organisation and development of measurement standards and with their maintenance (highest level)
- Industrial metrology has to ensure the adequate functioning of measurement instruments used in industry as well as in production and testing processes
- 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.

1.2 Industrial and scientific metrology

Industrial and scientific metrology are two of the three categories of metrology described in chapter 1.1.

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 in addition to accreditation and peer review.

1.2.1 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 EURAMET there are two additional subject fields: Flow and interdisciplinary metrology. There is no formal international definition of the subfields.

Table 1: Subject fields, subfields and important measurement standards, in which only the technical subject fields are included.

SUBJECT FIELD	SUBFIELD	Important measurment standards
MASS and related quantities	MASS measurment	MASS standards, standard balances, mass comparators
	Force and pressure	Load cells, dead-weight testers, force, moment and torque converters, pressure balances with oil/gas-lubricated piston cylinder assemblies, force-testing machines
	Volume and density Viscisity	Glass areometers, laboratory glassware, vibration densimeters, glass capillary viscometers, rotation viscometers, viscometry scale
Electricity and Magnetism	DC electricity	Gryogenic current comparators, Josephson effect and Quantum Hall effect, Zener diode references, potentiometric methods comparator bridges
	AC electricity	AC/DC converters, standard capacitors, air capacitors, standard inductances, compensators, wattmeters
	HF electricity	Thermal converters, calorimters, bolometers
	High current and high voltage	Measurement transformers of current and voltage, reference high voltage sources
LENGTH	Wavelenghts and interferometry	Stabilised lasers, Interferometers, laser interferometric measurement systems, interferometric comparators
	Dimensional metrology	Gauge blocks, line scales, step gauges, setting rings, plugs, high masters, dial gauges, measuring microscopes, optical flat standards, coordinate measuring machines, laser scan micrometers, depth micrometers

SUBJECT FIELD	SUBFIELD	Important measurement standards
LENGTH	Angular measurements	Autocolimators, rotary tables, angle gauges, polygons, levels
	Forms	Straightness, flatness, parallelism, squares, roundness standards, cylinder standards
	Surface Quality	Step height and groove standards, roughness standards, roughness measurement equipment
TIME and FREQUENCY	Time measurement	Caesium atomic clock, time interval equipment
	Frequency	Atomic clock and fountain, quartz oscillators, lasers, electronic counters and synthesisers, (geodetic length measuring tools)
THERMOMETRY	Temperature measurement by contact	Gas thermometers, ITS 90 fixed points, resistance thermometers, thermocouples
	Non-contact temperature measurement	High-temperature black bodies, cryogenic radiometers, pyrometers, Si photodiodes
	Humidity	Mirror dew point meters or electronic hygrometers, double pressure/temperature humidity generators
IONISING RADIATION and RADIOACTIVITY	Absorbed dose - High level industrial products	Calorimeters, calibrated high dose rate cavities, Dichromat dosimeters
	Absorbed dose - Medical products	Calorimeters, Ionisation chambers
	Radiation protection	Ionisation chambers, Reference radiation beams/fields, proportional and other counters, TEPC, Bonner neutron spectrometers
	Radioactivity	Well-type ionising chambers, Certified radioactivity sources, Gamma and alpha spectroscopy and radioactivity detectors

SUBJECT FIELD	SUBFIELD	Important measurment standards
PHOTOMETRY and RADIOMETRY	Optical radiometry	Cryogenic radiometer, detectors, stabilised laser reference sources, reference materials – Au fibres
	Photometry	Visible region detectors, Si photodiodes, quantum efficiency detectors
	Colorimetry	Spectrophotometer
	Optical fibres	Reference materials – Au fibres
FLOW	Gas flow (volume)	Bell provers, rotary gas meters, turbine gas meters, transfer meter with critical nozzles
	Flow of water (volume, mass and energy)	Volume standards, Coriolis mass-related standards, level meters, inductive flow meters, ultrasound flow meters
	Flow of liquids other than water	
	Anemometry	Anemometers
ACOUSTICS, ULTRASOUND and VIBRATION	Acoustical measurements in gases	Standard microphones, piston phones, condenser microphones, sound calibrators
	Accelerometry	Accelerometers, force transducers, vibrators, laser interferometer
	Acoustical measurements in liquids	Hydrophones
	Ultrasound	Ultrasonic power meters, radiation force balance
AMOUNT of SUBSTANCE	Environmental chemistry	Certified reference materials, mass spectrometers, chromatographs
	Clinical chemistry	
	Materials chemistry	Pure materials, certified reference materials
	Food chemistry	Certified reference materials
	Biochemistry	
	Micro biology	
	pH measurement	Certified reference materials, standard electrodes

1.2.2 Measurement standards

Definition [4]: 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 of 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 sub-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 standard are shown in figure 1 page 12. Metrology fields, subfields and important measurement standards are shown in table 1 (page 7) An international listing of all measurement standards does not exist.

1.2.3 Certified Reference Materials

A certified reference material (CRM) 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.

1.2.4 Traceability & Calibration

Definition of Traceability**:** A traceability chain is an unbroken chain of comparisons, all having stated uncertainties, see figure 1 (page 12).

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 obtained by using CRMs and reference procedures - see 1.2.3 and 1.2.5, pages 10 & 11.

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.

Definition of Calibration (Chapter 6, page 44): Set of operations that establish, under specified conditions, the relationship between values of quantities indicated 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.

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 provided for the instrument.

Three main reasons for having an instrument calibrated are:

- To ensure readings from the instrument are consistent with other measurements
- To determine the accuracy of the instrument readings
- To establish the reliability of the instrument i.e. that it can be trusted

The result of a calibration can be registered in a document called a calibration certificate or a calibration report.

1.2.5 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
- characterisation of reference materials including reference objects
- determination of reference values

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

Figure 1: The traceability chain

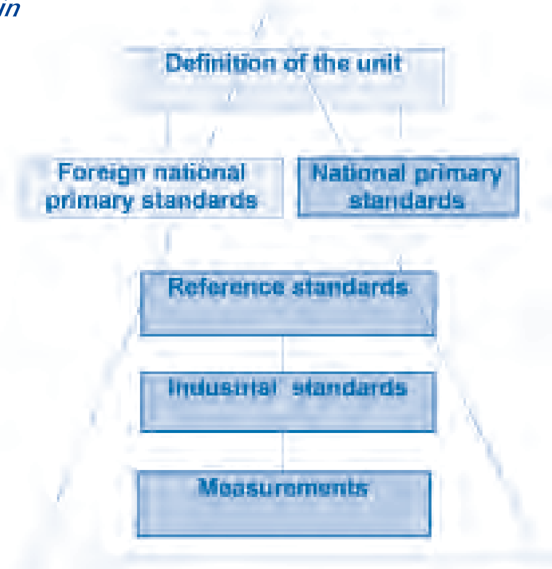
BIPM
(Bureau International des Poids et Mesures)

National Metrology Institutes or designated national laboratories

Calibration Laboratories, often accredited

Enterprises

End users



Uncertainty
increases down the traceability chain

The national metrological infrastructure

1.2.6 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 in, 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’ - Chapter 6, page 44. The main points of the GUM-method and its underlying philosophy are desribed below.

Example A measurement result is reported in a certificate on 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 7Ω where the resistance meter, according to the manufacturer's specifications, has an uncertainty of 0,081 mΩ, the result stated on the certificate is R = (1,000 053 ± 0,000 081) Ω

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.

The GUM uncertainty philosophy

1) *A measurement quantity X,* whose value is not known exactly, is considered as a stochastic variable with a probability function.
2) *The result x* of measurement is an estimate of the expectation value E(X).
3) *The standard uncertainty u(x)* is equal to the square root of an estimate of the variance V(X).
4) *Type A evaluation*
Expectation and variance are estimated by statistical processing of repeated measurements.
5) *Type B evaluation*
Expectation and variance are estimated by other methods. The most commonly used method is to assume a probability distribution e.g. a rectangular distribution, based on experience or other information.

The GUM method is 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 combined uncertainty is

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

4) Calculate the expanded uncertainty - multiply the combined uncertainty with the coverage factor k.

5) State the measurement result on the form:

$$Y = y \pm U$$

1.2.7 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 fulfils specifications 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 the ones 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.

1.3 Legal metrology

1.3.1 Scope of Legal Metrology

Legal Metrology encompasses all legislative, administrative and technical procedures, which work to ensure measurement quality and credibility.

Legal Metrology focuses on the need for confidence and equity in measurements which directly concern the public, especially those measurements relating to efficiency in commerce, public health, safety and environmental monitoring.

The scope of legal metrology depends on national regulations and may be different from country to country. In general, most countries have legislation to control trade measurements.

A few countries also regulate measurements in the following areas:

- public health and human safety (e.g. in the medical field and road safety)
- environmental protection and pollution monitoring
- resource monitoring and control

Measurements enter into practically all commercial transactions from the trading of goods. In ordinary commercial transactions, legal metrology ensures that during the sale of any commodity in loose form, the actual delivery to the purchaser is not less than the quantity contracted and paid for.

In the case of pre-packaged goods, the primary requirement is that the packages intended for retail sale should be marked with the correct statement of net quantity and the name of the packer, in such style and form as to be readily seen by the purchaser. In addition, the packing of certain commodities may be in rationalised standard quantities to facilitate quantity and price comparison. Net content inspection of pre-packages carried out by the legal metrology authorities protects consumers, who cannot verify the net quantity of contents.

Legal metrology therefore ensures fair trade practices and maintains a competitive marketplace. It also encourages manufacturers, distributors and retailers to follow good manufacturing and distribution practices.

Legal control on measurements involving public health and human safety is equally important from the consumer protection viewpoint. For example, a clinical thermometer or a blood pressure instrument which is not properly verified, may lead to wrong diagnosis and incorrect medication. Chemical metrology monitors food and toxic substances in the human body while the breath analyser and radar speed measurement helps to ensure safety on the roads.

The field of environmental protection and pollution monitoring is heavily regulated and is already one of the most important measurement activities of modern legal metrology. As the planet is threatened with many of its precious resources (water, minerals, oil and gas, fish, etc.), prices tend to increase thereby increasing the need of more accurate measurement.

Countries are increasingly regulating resource monitoring and control, based on adequate and accurate measurement. It is expected that in this 21st century, environmental protection and resource monitoring, will become the most important areas of legal metrology, on par with trade metrology.

1.3.2 Requirements for National Legal Metrology Legislation

A national law on metrology usually provides for the following:

- Legal units of measurement
- Physical representation of legal units
- Hierarchy of measurement standards – their maintenance and custody
- Technical regulations of measuring instruments covering metrological technical and administrative requirements
- Metrological control on measuring instruments
- Metrological control on prepackaged commodities
- Authority responsible for legal metrology
- Financial provisions
- Offences and penalties

1.3.2.1 Legal units of measurement

The legal units of measurement accepted by most countries are the SI units (i.e. the International System of Units), their decimal multiples and submultiples as indicated by the use of SI prefixes and certain non-SI units specified by relevant regulations. The International System of Units is the revised and modern form of the metric system. SI has been recognised and recommended by the General Conference on Weights and Measures (CGPM) and the International Organisation of Legal Metrology (OIML).

Details about the SI system can be found in Chapter 3, page 34

1.3.2.2 Physical representation of legal units

In order to translate the legal units into practice for application in various fields, they have to be physically realised. A measurement standard can be a physical measure, measuring instrument, reference material or measuring system intended to define, realise, conserve or reproduce a unit or one or more values of quantity to serve as a reference. The International Standard (or Prototype) of the kilogram is a cylindrical piece of a platinum-iridium alloy of diameter and height each 39 mm which is kept at the International Bureau of Weights and Measures (BIPM) in Sèvres, near Paris. Each member country of the Metre Convention gets a copy of the international prototype duly certified by BIPM. This constitutes the national standard of the kilogram. Primary standards of other units may be realised in certain well equipped national metrology institutes by preparing such objects or reproducing such phenomena as may be necessary for the purpose.

With the exception of the kilogram whose definition is based on a physical artifact, the definitions of all other base units are now based on natural phenomena which can be reproduced at the level of national laboratories. The realisation of these base units is a complex task; however the advantage of this is that in principle, it can be carried out at any place and at any time.

1.3.2.3 Hierarchy of standards

National measurement standards, which are compared at regular intervals to international standards of higher accuracy, serve as the basis for assigning values to other standards of the quantity concerned. The custodian of national measurement standards is usually a laboratory called the national metrology institute, the national bureau of standards or the national bureau of weights and measures.

The national standards are not put into use for day to day work. They are used to calibrate secondary standards of the country, which are themselves normally used to calibrate working standards. Working standards are used by the national legal metrology services or calibration laboratories to verify or calibrate material measures and measuring instruments used in trade and industry.

The standards mentioned above represent a hierarchy, starting with international standards at the apex and going all the way down to working standards. There is no general requirement as far as the accuracy of standards is concerned. A working standard in one location may be good enough to serve as a secondary or even a national standard in another.

The aim of having a hierarchy of standards is to ensure traceability of measurements made in a country. Traceability of a measurement is the assurance that it can be related to a national or international standard. Traceability, as defined in the International Vocabulary of Basic and General Terms of Legal Metrology, is the property of the result of a measurement or the value of a measurement standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties.

1.3.2.4 Technical regulations on measuring instruments

Technical regulations for measuring instruments used in areas of public interest such as trade (weighing instruments, weights, measuring systems for liquids, electricity meters, taximeters), health care (clinical thermometers, blood pressure instruments), environmental protection (gas chromatographs, atomic absorption spectrometers), traffic surveillance (evidential breath analysers, instruments for measuring vehicle exhaust emissions) or safety at work (dosimeters) are generally prescribed under subsidiary legislation which covers:

- metrological requirements
- technical requirements
- administrative requirements

Metrological requirements are intended to set the maximum permissible errors for instruments and the conditions under which they must be met. They may also specify measuring ranges, the indication of measurements, the verification procedures, etc.

Technical requirements are intended to set the essential general design characteristics of instruments without imposing restrictions on technical development in order to ensure that:

- their metrological qualities are maintained in use
- measurement results are simple and unambiguous
- the risks of fraud are eliminated as far as possible

Administrative requirements lay down the scope and field of application of the regulations, the power for examination of the instruments for the purpose of ascertaining compliance to the metrological and technical requirements, the obligations of users of measuring instruments and so on.

1.3.2.5 Metrological control of measuring instruments

Metrological control includes:

- type or pattern approval
- initial verification
- subsequent verification
- inspection or supervision of the use of measuring instruments

In a type or pattern approval scheme, one or more instruments of the same pattern are subjected to rigorous tests prescribed under the law. The objective of all such tests is to ensure that the instruments of the pattern concerned, comply with the relevant statutory requirements and are suitable for use in the regulated area. Accordingly, they are expected to provide reliable measurement results over a defined period of time and under varied conditions of use. Pattern approval is usually the task of the national metrology institute or the legal metrology service, depending on the situation of the country in question.

If an OIML Recommendation exists and if it is applied for pattern evaluation, an OIML certificate may be issued on request from the manufacturer.

Initial verification means the verification of a measuring instrument which has not been verified previously. Under the law, every such item to be used in regulated areas, has to be verified and stamped before being released for use or even sale to the user. Generally the accuracy requirements for initial verification are more stringent than those for subsequent verification or inspection. Initial verification is normally the responsibility of the legal metrology service or other authorised organisation. In the European Union, the manufacturer is responsible for the initial verification of certain types of instruments e.g. non-automatic weighing instruments.

Subsequent verification means any verification of a measuring instrument after an initial verification. It includes:

- mandatory periodical verification
- verification after repair

The national regulations of several countries provide that measuring instruments used in regulated areas (trade, medical diagnosis, environmental protection and monitoring, etc.) have to be verified periodically at regular intervals of one year, two years or longer, depending on the type of instrument, to ensure that the individual instruments are still within their prescribed limits of error and satisfy all other metrological and technical requirements prescribed. The law often provides that any measuring instrument which is repaired has to be re-verified and stamped even if the period of validity of its previous verification has not expired.

Inspection or supervision is the control exercised in respect of the manufacture, import, installation, use, maintenance and repair of measuring instruments, performed in order to check whether the metrology law and regulations are properly complied with. It includes the checking of correctness of quantities indicated on and contained in pre-packages.

Inspection is an important element of metrological control from the consumer protection viewpoint. Inspections are carried out without notice and are very often initiated as a result of complaints from the public.

1.3.2.6 Control of pre-packaged commodities

In recent decades, the take-off of pre-packaged commodities has received considerable impetus because of the ease and convenience with which they can be transported and marketed. Weighing and measuring in the presence of the purchaser is now tending to be gradually reduced and is expected to be limited to a few selected items in the near future.

Requirements for the sale of pre-packaged goods are part of national legislation in many countries and they usually provide for the following:

- labelling requirements
- standardisation of pack sizes
- metrological control
- prevention of deceptive packaging

1.3.2.7 Legal metrology authority

The structure of the organisation concerned with legal metrology varies from one country to another. The metrology infrastructure may consist of the following organs:

a) a Scientific Body, which is the national metrology institute responsible for:

- the safe custody, maintenance and traceability of national standards
- the accuracy of standards of the next lower accuracy level for use inside the country by comparison with the national standards
- scientific and technical work in all fields of metrology

b) a Central co-ordinating and Directing Body responsible for:

- the planning and coordination of the enforcement activities of local bodies responsible for metrological control
- the preparation of draft technical legislation in the field of legal metrology
- supporting the work of other organisations related to legal metrology
- organising training in the field of legal metrology
- representing the country in international and regional activities related to legal metrology

c) local bodies responsible for field operation and law enforcement which include the following functions:

- the supervision and control of the manufacture, sale and repair of measuring instruments
- metrological control on measuring instruments
- the control of pre-packaged commodities

1.3.2.8 Financial Provisions

Most legal metrology services in the world charge fees for their verification and pattern evaluation activities, to meet part of their costs of operation (equipment, standards, salary, transport, etc.).

1.3.2.9 Offences and penalties

Offences under the law of legal metrology include:

- the use of a measuring instrument which is incorrect, tampered or not duly verified and stamped
- the manufacture, import or sale of measuring instruments which do not comply with the regulations
- pre-packing, distributing, offering for sale or selling pre-packaged goods that are short in quantity, not properly labelled or not complying with other requirements of the regulations

In order to have an effective compliance with legal metrology legislation, penalties including fine and/or imprisonment are normally provided.

1.3.3 The European Single Market

Since the creation of the EEC (European Economic Community) through the Treaty of Rome back in 1958, one of the main guiding principles has been the removal of barriers to trade whether these are tariff barriers or technical barriers. It was recognised that the harmonisation of technical requirements was one of the key elements to creating the single market. In the field of legal metrology, including pre-packaging, the European Council Directives, listed in Table 2 below, have been passed for implementation by Member States.

A new arrangement entitled 'A New Approach to Technical Harmonisation and Standards' was formally agreed by Council resolution in May 1985, where instead of detailed technical requirements, only essential requirements would be included in the Directives. However, these Directives would have mandatory application in Member States. The latter would be required, subject to transitional arrangements, to revoke both existing national regulations and those regulations implementing 'Old Approach' Directives, in relation to new instruments to be placed on the market and put into use. The 'New Approach' provides an alternative way of meeting the essential requirements which can either be met by the direct application of the essential requirements or by the application of agreed harmonised standards. The standards route provides a greater degree of certainty for the manufacturer, that both product design and manufacturing process will meet the essential requirements.

Table 2 – Some Useful European Council Directives in the field of legal metrology

AREA	EEC DIRECTIVE
• Units of measurement	80/181/EEC
• Exhaust gas analysers • Water meters • Active electrical energy meters • Heat meters • Gas meters and volume conversion devices • Dimensional measuring instruments • Automatic weighing instruments • Material measures • Systems for the continuous and dynamic measurement of quantities of liquids other than water • Taximeters	Directive 2004/22/EC
• Alcohol meters and alcohol hydrometers	Directive 76/765/EC
• Alcohol tables	Directive 76/766/EC
• Tyre pressure gauges for motor vehicles	Directive 86/217/EC
• Pre-packaged products	Directive 76/211/EEC
• Pre-packaged liquids	Directive 75/106/EEC
• Bottles used as measuring containers	Directive 75/107/EEC

1.3.3.1 The e-marking of pre-packages

In order to facilitate the free movement of goods, the Member States of the European single market have agreed on common rules for pre-packages within the range of 5 g to 10 kg and 5 mL to 10 L. Packages may be marked with an 'e' provided they comply with the European Council Directives 76/211/EEC or 75/106/EEC. Packages bearing the e-mark will be checked only in the country of origin and can be freely marketed within the European Community and in Iceland, Liechtenstein and Norway, signatories of the Agreement of the European Economic Area (EEA). If the country of origin does not belong to these States which form the 'Single Market', the packages will be checked at the point of entry into the 'Single Market' at the importer's site.

The e-mark acts as a 'metrological' passport since it is recognised throughout the European market of about 500 million consumers. The e-mark special form and the relative dimensions are given in the European Directives.

The metrological or accuracy requirements for pre-packages, bearing the e-mark are similar to those recommended by OIML, which are:

- The actual net quantity shall not be less, on average, than the nominal quantity
- Only a small proportion (not more than 2.5 %) of the number of pre-packages in a batch may be deficient by more than the tolerable negative errors, which are the same as the tolerable deficiencies recommended by OIML
- There shall be no pre-package containing less than twice the tolerable negative error

However, the European Directives for e-marking cover only pre-packages within the range 5 g to 10 kg or 5 mL to 10 L, while the international recommendation (OIML R 87) can be applied to pre-packages of any predetermined constant nominal quantity up to 50 kg or 50 L. The European Directives also provide for both single and double sampling plans including special sampling plans for destructive testing, while OIML R 87 provides for only a single sampling plan.

The packer (or importer, if the pre-packages are produced outside the European market) is responsible for ensuring that his pre-packages meet the requirements of the European Directives. The measurement or check shall be carried out by means of a legal measuring instrument suitable for the purpose with the total uncertainty of measurement not exceeding one-fifth of the tolerable negative error of the pre-package. In case of imports from non-EEC countries, the importer may instead of measuring and checking, provide evidence that he is in possession of all the necessary guarantees enabling him to assume responsibility. The importer must provide a certificate, issued by the competent department of a Member State or an EU accepted competent department in the exporting country, stating the compliance of the packer's quantity control system to the Directive for each type of product.

1.3.3.2 Measuring instruments

Directive 71/316/EEC, which contains requirements for all categories of measuring instruments and other Directives covering individual categories of measuring instruments (see list of European Directives Table 2, page 22) provide the basis for harmonisation. Measuring instruments, 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 pattern approvals.

An important step towards common European requirements on measuring instruments was taken with the introduction of the Measuring Instruments Directive (MID). The MID aims at the elimination of technical barriers to trade and will regulate the marketing and use of the following types of measuring instruments:

- water meters
- measuring systems for liquids other than water
- automatic weighing instruments
- gas meters
- electrical energy meters and measurement transformers
- material measures (length and capacity)
- heat meters
- exhaust gas analysers
- taximeters
- dimensional measuring instruments

The MID is based on the Non automatic Weighing Instrument Directive which is a 'New approach' Directive, which came into force in 1993. With this approach, the instruments mentioned above will have to meet the essential requirements. The manufacturer may refer to harmonised European standards. Where instruments complying with these harmonised standards are concerned, it will be assumed that they meet the requirements of the Directive, meaning that application of the harmonised standards would facilitate access to market.

A two-stage conformity assessment procedure is provided for electronic measuring instruments. In the first stage, a type examination is performed by a third-party certification body. In the second stage, initial verification of the individual instruments can be carried out by the manufacturer provided that an approved and supervised quality system is being implemented. The verification of the individual instruments must otherwise be carried out by a recognised third-party certification body. Member States are notified of certification bodies.

These notified bodies must possess the technical competence and independence stipulated by the Directive or the appropriate harmonised standard, thus enabling them to perform technical and administrative tasks. They may either be private or governmental organisations. Manufacturers are free to choose among these European bodies.

Measuring instruments complying with the appropriate Directives must carry a CE-mark and the supplementary legal metrology mark, before they are marketed in the European Economic Area, provided they have passed an EC conformity assessment procedure.

The binding legal control of measuring instruments, as mentioned in the Directive, is to be left to each member country. Requirements to be met by instruments after they have been put into use have not been harmonised. Re-verification, inspections and verification validity periods may consequently be laid down by member countries on the basis of their own national legislation. Member States may lay down legal requirements for measuring instruments which are not listed in the Measuring Instruments Directive (MID).

With the implementation of the MID, means that a single approval by one notified body will give the manufacturer or the exporter access to all EU markets.

2. METROLOGICAL ORGANISATION

2.1 International infrastructure

2.1.1 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.

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

The objectives of the CIPM MRA are 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.

BIPM Key comparison database

The BIPM key comparison database contains the results of key and supplementary comparisons together with the lists of peer-reviewed and approved Calibration and Measurement Capabilities CMCs of the NMIs. In 2003, there were approximately 13,500 individual CMCs published in the BIPM key comparison database, all of which have undergone a process of peer evaluation by NMI experts under the supervision of the Regional Metrology Organisations. This is co-ordinated internationally by the Joint Committee of the Regional Metrology Organisations and BIPM JCRB.

Figure 2: The Metre Convention organisation

The Metre Convention
International convention established in 1875 with 51 member states in 2003.

CGPM Conférence Générale des Poids et Mesures
Committee with representatives from the Metre Convention member states. First conference held in 1889 and meets every 4th year. Approves and updates the SI-system with results from fundamental metrological research.

CIPM Comité Internationale des Poids et Mesures
Committee with 18 representatives from CGPM. Supervises BIPM and supplies chairmen for the Consultative Committees.
Co-operates with other international metrological organisations.

- CEN*
- IEC*
- ISO*
- Others

BIPM
Bureau International des Poids et Mesures

International research in physical units and standards.

Administration of interlaboratory comparisons of the national metrology institutes and designated laboratories.

Consultative Committees:

- **CCAUV** CC for Acoustics, Ultrasound and Vibrations
- **CCEM** CC for Electricity and Magnetism
- **CCL** CC for Length
- **CCM** CC for Mass and related quantities
- **CCPR** CC for Photometry and Radiometry
- **CCQM** CC for Amount of Substance
- **CCRI** CC for Ionising Radiation
- **CCT** CC for Thermometry
- **CCTF** CC for Time and Frequency
- **CCU** CC for Units

*) See Accronyms

2.1.3 National Metrology Institutes

A National Metrology Institute, NMI is an institute designated by national decision to develop and maintain national measurement standards for one or more quantities.

Some countries operate a centralised metrology organisation with one NMI. The NMI may devolve the maintenance of specific standards to certain laboratories without these having the status of a NMI. Other countries operate a decentralised organisation with a multiplicity of institutes, all having the status of a NMI.

An NMI represents the country internationally in relation to the national metrology institutes of other countries, in relation to the Regional Metrology Organisations and to the BIPM. The NMIs are the backbone of the international metrology organisation shown on the figure in chapter 2, page 27

A list of NMIs is available via the Regional Metrology Organisations, e.g. in Europe the NMIs can be found in the EURAMET Directory.

2.1.4 Primary laboratories

A nominated laboratory which:

- is internationally recognised for the realisation of a metrology base unit at the primary level, or a derived unit at the highest achievable international level
- carries out internationally recognised research within specific sub-fields
- maintains and further develops the unit concerned by maintaining and further developing primary standards
- participates in comparisons at the highest international level

Primary laboratories are designated by the NMI of the country.

2.1.5 Reference laboratories

A nominated laboratory which is capable of calibrating a given measurement quantity at the highest level of accuracy in the country, traceable to a primary laboratory.

Reference laboratories are designated by the NMI of the country.

2.1.6 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 an 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.

2.1.7 ILAC

The International Laboratory Accreditation Co-operation ILAC is an international cooperation between the various laboratory accreditation schemes operated throughout the world.

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.

2.1.8 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 organisation 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.

2.2 European infrastructure

The geographical coverage of the regional metrology organisations RMOs are shown on the RMO - see RMO map - in appendix 1

2.2.1 Metrology - EURAMET

EURAMET 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. EURAMET is the Regional Metrology Organisation for Europe under the CIPM MRA, see chapter 2, page 26

EURAMET is a co-operative voluntary organisation between the national metrology institutes in the EU, EFTA and EU Accession States. The European Commission is also a member. In 2003, there were 27 members and 12 corresponding applicants and corresponding NMIs, several countries are in the process of applying for membership.

EURAMET has the following specific tasks:

- Provision of a framework for collaborative research projects of 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

2.2.2 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 NMIs, designated national laboratories and accredited laboratories. The trend is for NMIs and designated laboratories also to seek third-party assessment of their quality systems through accreditation, certification or peer assessment.

2.2.3 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.

2.2.4 EUROLAB

EUROLAB is the European Federation of National Associations of Measurement, Testing and Analytical Laboratories, covering around 2000 European laboratories. EUROLAB is a voluntary co-operation representing and promoting the views of the laboratory community technically and politically, by co-ordinating actions relating to, for example, the European Commission, European standardisation and international matters.

EUROLAB organises workshops and symposia and produces position papers and technical reports. Many laboratories dealing with metrology are also members of EUROLAB.

2.2.5 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 EURAMET co-operate 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.

2.2.6 COOMET

COOMET is an organisation corresponding to EURAMET with members from central and East European countries.

2.3 Lebanese infrastructure

2.3.1 Metrology

The Lebanese metrological organisation is decentralised and consists of calibration laboratories under the supervision of the Ministry of Economy and Trade. There are no primary laboratories in Lebanon.

National Metrology Institute

The Ministry of Economy and Trade has the role as the Lebanese NMI, (see chapter 2, page 28) which represents Lebanon in international metrological organisations as well as designated reference laboratories.

Reference laboratories

In Lebanon, only an accredited laboratory can be designated as a reference laboratory. Since accreditation requires international traceability, reference laboratories in Lebanon will have traceability to internationally recognised standards.

At the time of writing, there are no reference laboratories in Lebanon. By the end of 2008, it is planned to have at least 2 calibration laboratories accredited and to designate the best qualified laboratories as Lebanese reference laboratories.

Table 3: Calibration laboratories in Lebanon

(sub) Field	Calibration laboratory	Technical details	Expected Accredited	Contact
Electrical	Liban Cables SAL	www.libancables.com.lb	2008	Samir Saliba
Length	IRI	www.iri.org.lb	2008	Elias Maalouf
Mass	IRI	www.iri.org.lb	2008	Director Imad Hage Chehade
Volume	IRI	www.iri.org.lb	2008	Director Imad Hage Chehade
Force	IRI	www.iri.org.lb	2008	Director Imad Hage Chehade
Pressure	IRI	www.iri.org.lb	2008	Director Imad Hage Chehade
Temperature	IRI	www.iri.org.lb	2008	Director Imad Hage Chehade
Flow	IRI	www.iri.org.lb	2008	Director Imad Hage Chehade
Temperature	University Sct. Joseph	www.usj.edu.lb	2008	Doyen Toufic J. Rizk
Humidity	University Sct. Joseph	www.usj.edu.lb	2008	Doyen Toufic J. Rizk
Viscosity	University Sct. Joseph	www.usj.edu.lb	2008	Doyen Toufic J. Rizk
Photometry	University Sct. Joseph	www.usj.edu.lb	2008	Doyen Toufic J. Rizk
Ionising radiation	Lebanese Atomic Energy Commission	www.cnrs.edu.lb	2008	Youssef Assafiri yassafir@cnrs.edu.lb

2.3.2 Accreditation

- **Accreditation body**

The Lebanese accreditation body is established under the law on "The establishment of Lebanese Accreditation Council (COLIBAC)". The accreditation body was formed during 2006 and is expected to offer accreditations after one year of becoming operational. Within a few years, COLIBAC plans to sign the ILAC MRA, (see 2.1.7 page 29) and COLIBAC will accredit testing and calibration laboratories.

- **Accredited laboratories**

As of now, there are four accredited laboratories in Lebanon, all at IRI, accredited for microbiology, chemical and analysis of food, physical chemistry and central laboratory for bread and wheat. The number of accredited laboratories is expected to double by the end of 2008 . For Calibration laboratories working on accreditation, see Reference laboratories (Table 3, page 33).

2.3.3 Legal metrology

Legislation on legal metrology in Lebanon is under preparation.

3. 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.

The tables of units below (table 4 - 11) show the following:

SI units

Units outside SI

table 8	Units accepted because they are widely used, page 40
table 9	Units to be used within specific subject areas, page 40
table 10	Units to be used within specific subject areas and whose values are experimentally determined, page 41

SI Prefixes table 2, page 42

Table 4: SI base units (2, Chapter 6, page 44)

Quantity	Base unit	Symbol
length	metre	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
thermodynamic temperature	kelvin	K
amount of substance	mole	mol
luminous intensity	candela	cd

Table 5: Examples of SI derived units expressed in SI base units (2, Chapter 6, page 44)

Derived quantity	Derived unit	Symbol
area	square metre	m^2
volume	cubic metre	m^3
speed, velocity	metre per second	$m \cdot s^{-1}$
acceleration	metre per second squared	$m \cdot s^{-2}$
angular velocity	radian per second	$rad \cdot s^{-1}$
angular acceleration	radian per second squared	$rad \cdot s^{-2}$
density	kilogram per cubic metre	$kg \cdot m^{-3}$
magnetic field intensity, (linear current density)	ampere per metre	$A \cdot m^{-1}$
current density	ampere per cubic metre	$A \cdot m^{-2}$
moment of force	newton metre	$N \cdot m$
electric field strength	volt per metre	$V \cdot m^{-1}$
permeability	henry per metre	$H \cdot m^{-1}$
permittivity	farad per metre	$F \cdot m^{-1}$
specific heat capacity	joule per kilogram kelvin	$J \cdot kg^{-1} \cdot K^{-1}$
amount-of-substance concentration	mol per cubic metre	$mol \cdot m^{-3}$
luminance	candela per square metre	$cd \cdot m^{-2}$

3.1 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 represented by the wavelength of radiation from an iodine-stabilised helium-neon laser.

These redefinitions have reduced the relative uncertainty from 10^{-7} to 10^{-11} m.

SI base unit definitions

The metre is the length of the path travelled by light in a 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 10^{12} hertz and has a radiant intensity in that direction of 1/683 watts per steradian.

Table 6. SI derived units with special names and symbols

Derived quantity	SI derived unit Special name	Symbol Special symbol	In SI units	In SI base units
frequency	hertz	Hz		s^{-1}
force	newton	N		$m \cdot kg \cdot s^{-2}$
pressure, stress	pascal	Pa	N/m^2	$m^{-1} \cdot kg \cdot s^{-2}$
energy, work, quantity of heat	joule	J	$N \cdot m$	$m^2 \cdot kg \cdot s^{-2}$
power, radiant flux	watt	W	J/s	$m^2 \cdot kg \cdot s^{-3}$
electric charge, quantity of electricity	coulomb	C		$s \cdot A$
electric potential difference, electromotive force	volt	V	W/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-1}$
electric capacitance	farad	F	C/V	$m^{-2} \cdot kg^{-1} \cdot s^4 \cdot A^2$
electric resistance	ohm	Ω	V/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-2}$
electric conductance	siemens	S	A/V	$m^{-2} \cdot kg^{-1} \cdot s^3 \cdot A^2$
magnetic flux	weber	Wb	$V \cdot S$	$m^2 \cdot kg \cdot s^{-2} . A^{-1}$
magnetic induction, magnetic flux density	tesla	T	Wb/m^2	$kg \cdot s^{-2} \cdot A^{-1}$
inductance	henry	H	Wb/A	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-2}$
luminous flux	lumen	lm	Cd . sr	$m^2 \cdot m^{-2} \cdot cd = cd$
illuminance	lux	lx	Lm/m^2	$m^2 \cdot m^{-4} \cdot cd = m^{-2} \cdot cd$
activity (of a radionuclide)	becquerel	Bq		s^{-1}
absorbed dose, kerma, specific energy (imparted)	gray	Gy	J/kg	$m^2 \cdot s^{-2}$
dose equivalent	sievert	Sv	J/kg	$m^2 \cdot s^{-2}$
plane angle	radian	rad		$m \cdot m^{-1} = 1$
solid angle	steradian	sr		$m^2 \cdot m^{-2} = 1$

3.2 SI derived units

A derived unit is a unit of measurement of a derived quantity in a given system of quantities - (4, chapter 6, page 44)

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 5, page 35.

The CGPM has approved special names and symbols for some derived units, as shown in table 6, page 37.

Some base units are used in different quantities, as shown in table 7. 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 7 Examples of SI derived units whose names and symbols include SI derived units with special names and symbols - (2, chapter 6, page 44)

Derived quantity	Derived unit	Symbol	In SI base units
dynamic viscosity	pascal second	Pa · s	$m^{-1} \cdot kg \cdot s^{-1}$
moment of force	newton metre	N · m	$m^2 \cdot kg \cdot s^{-2}$
surface tension	newton per metre	N/m	$kg \cdot s^{-2}$
angular velocity	radian per second	rad/s	$m \cdot m\text{-}1 \cdot s^{-1} = s^{-1}$
angular acceleration	radian per second squared	rad/s^2	$m \cdot m^{-1} \cdot s^{-2} = s^{-2}$
heat flux density, irradiance	watt per square metre	W/m^2	$kg \cdot s^{-3}$
heat capacity, entropy	joule per kelvin	J/K	$m^2 \cdot kg \cdot s^{-2} \cdot K^{-1}$
specific heat capacity,	joule per kilogram		

Derived quantity	Derived unit	Symbol	In SI base units
specific entropy	kelvin	J/(kg·K)	$m^2 \cdot s^{-2} \cdot K^{-1}$
specific energy	joule per kilogram	J/kg	$m^2 \cdot s^{-2}$
thermal conductivity	watt per metre kelvin	W/(m·K)	$m \cdot kg \cdot s^{-3} \cdot K^{-1}$
energy density	joule per cubic metre	J/m^3	$m^{-1} \cdot kg \cdot s^{-2}$
electric field strength	volt per metre	V/m	$m \cdot kg \cdot s^{-3} \cdot A^{-1}$
electric charge density	coulomb per cubic metre	C/m^3	$m^{-3} \cdot s \cdot A$
electric flux density	coulomb per square metre	C/m^2	$m^{-2} \cdot s \cdot A$
permittivity	farad per metre	F/m	$m^{-3} \cdot kg^{-1} \cdot s^4 \cdot A^2$
permeability	henry per metre	H/m	$m \cdot kg \cdot s^{-2} \cdot A^{-2}$
molar energy	joule per mole	J/mol	$m^2 \cdot kg \cdot s^{-2} \cdot mol^{-1}$
molar entropy, molar heat capacity	joule per mole kelvin	J/(mol·K)	$m^2 \cdot kg \cdot s^{-2} \cdot K^{-1} \cdot mol^{-1}$
exposure (x and * rays)	coulomb per kilogram	C/kg	$kg^{-1} \cdot s \cdot A$
absorbed dose rate	gray per second	Gy/s	$m^2 \cdot s^{-3}$
radiant intensity	watt per steradian	W/sr	$m^4 \cdot m^{-2} \cdot kg \cdot s^{-3} = m^2 \cdot kg \cdot s^{-3}$
radiance	watt per square metre steradian	$W/(m^2 \cdot sr)$	$m^2 \cdot m^{-2} \cdot kg \cdot s^{-3} = kg \cdot s^{-3}$

3.3 Units outside the SI

Table 8, page 40, 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 9, page 40, gives examples of units outside the SI that are accepted for use within specific subject areas.

Table 10, page 41, gives units outside the SI which are accepted for use within specific subject areas and whose values are experimentally determined.

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

Table 8 Units outside SI which are accepted

Quantity	Unit	Symbol	Value in SI units
time	minute	min	1 min = 60 s
	hour	h	1 h = 60 min = 3600 s
	day	d	1 d = 24 h
plane angle	degree	°	1° = (π/180) rad
	minute	′	1′ = (1/60) ° = (π/10 800) rad
	second	″	1″ = (1/60) ′ = (π/648 000) rad
	nygrad	gon	1 gon = (π/200) rad
volume	litre	l, L	1 l = 1 dm^3 = 10^{-3} m^3
mass	metric tonne	t	1 t = 103 kg
pressure in air, fluid	bar	bar	1 bar = 105 Pa

Table 9: Units outside the SI which are accepted for use within specific subject areas

Quantity	Unit	Symbol	Value in SI units
length	mile nautical		1 nautical mile = 1852 m
Speed	knot		1 nautical mile per hour = (1852/3600) m/s
Mass	carat		1 carat = 2 x 10^{-4} kg = 200 mg
linear density	tex	tex	1 tex = 10^{-6} kg/m = 1 mg/m
strength of optical systems	dioptre		1 dioptre = 1 m^{-1}
pressure in human body fluids	millimetres of mercury bar	mmHg	1 mmHg = 133 322 Pa
Area	are	a	1 a = 100 m^2
Area	hectare	ha	1 ha = 10^4 m^2
pressure	bar	bar	1 bar = 100 kPa = 105 Pa
length	ångström	Å	1 Å = 0,1 nm = 10^{-10} m
Cross-section	barn	b	1 b = 10^{-28} m^2

Table 10: units outside the SI which are accepted within specific subject areas and whose values are experimentally determined - (2, chapter 6, page 44)

Quantity	Unit	Symbol	Defenition	In SI units
energy	electron-volt	eV	1 eV is the kinetic energy of an electron passing a potential difference of 1 V in vacuum.	1 eV = 1,602 177 33 (49) · 10^{-1} J
Mass	atomic mass unit	u	1 u is equal to 1/1 of the rest mass of a neutral atom of the nuclid ^{12}C in the ground state.	1 u = 1,660 540 2 (10) · 10-27 kg
length	astronomical unit	ua		1 ua = 1,495 978 706 91 (30).10^{11} m

3.4 SI prefixes

The CGPM has adopted and recommended a series of prefixes and prefix symbols, shown in table 11, page 42.

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 μkg

4. A prefix must not be written alone.
   Example: 109/m3 must not be written as G/m3

Table 11: SI prefixes - (2, chapter 6, page 44)

Factor	Prefix name	Symbol	Factor	Prefix name	Symbol
10^{1}	deca	da	10^{-1}	deci	d
10^{2}	hecto	h	10^{-2}	centi	c
10^{3}	kilo	k	10^{-3}	milli	m
10^{6}	mega	M	10^{-6}	micro	µ
10^{9}	giga	G	10^{-9}	nano	n
10^{12}	tera	T	10^{-12}	pico	p
10^{15}	peta	P	10^{-15}	femto	f
10^{18}	exa	E	10^{-18}	atto	a
10^{21}	zetta	Z	10^{-21}	zepto	z
10^{24}	yotta	Y	10^{-24}	yocto	y

4. INFORMATION ON METROLOGY - LINKS

Info about ...	Source	Contact
Accreditation Accredited laboratories	EA	www.european-accreditation.org
Analytical chemistry labs	EURACHEM	www.eurachem.ul.pt
Calibration and testing Laboratories	EUROlab	www.eurolab.org
Intercomparisons	EUROMET	www.euromet.org
International metrology organisations	BIPM	www.bipm.org
Key comparisons	BIPM key comparison database	www.bipm.org/kcdb
Legal metrology in Europe	WELMEC	www.welmec.org
Legal metrology, international	OIML	www.oiml.org
National Metrology Institutes	BIPM EUROMET	www.bipm.org www.euromet.org
Reference materials for chemical analysis	IRMM COMAR database	www.irmm.jrc.be
The SI system	BIPM	www.bipm.org

5. SOME USEFUL ADDRESSES

- Asia-Pacific Legal Metrology Forum (APLMF), NMIJ/AIST Tsukuba Central 3-9 1-1-1 Umezono, Tsukuba, Ibaraki, 305-8563 Japan Tel: + 81 29 861 4362 Fax: +81 29 861 4393 E-mail:e.sec@aplmf.org web site: http://www.aplmf.org
- Bureau International des Poids et Mesures (BIPM), F-92312 Sèvres Cedex, France Tel: +33 14 50 77 001 Fax: +33 14 53 48 670 web site: http://www.bipm.fr
- Euro-Asian Cooperation of State Metrology Institutions (COOMET), Belarus Tel: +375 17 233 2424 Fax: +375 17 288 0938 E-mail: coomet@coomet.belpak.minsk.by web site: http://www.coomet.org
- European cooperation in legal metrology (WELMEC), WELMEC Secretariat, BEV Arltgasse 35, A-1160 Vienna, Austria Tel: +43 1 21176 3608 Fax: +43 1 49 20 875 E-mail: welmec@metrologie.at web site: http://www.welmec.org
- International Laboratory Accreditation Cooperation (ILAC), ILAC Secretariat, c/oNational Association of Testing Authorities (NATA), 7 Leeds Street, Rhodes NSW 2138, Australia Tel: +61 2 97 368 374 Fax: +61 2 97 368 373 E-mail: ilac@nata.asn.au web site: http://www.ilac.org
- International Measurement Confederation (IMEKO), P.O.B. 457 H-1371, Budapest, Hungary Tel/Fax : +36 1 353 1562 E-mail: imeko.ime@mtesz.hu web site: http://www.imeko.org
- Internationa l Organisation for Standardisation (ISO), ISO Central Secretariat, Case postale 56, CH-1211 Geneva, Switzerland Tel: +41 22 749 01 11 Fax: +41 22 733 34 30 web site: http://www.iso.ch
- International Organisation of Legal Metrology (OIML), International Bureau of Legal Metrology, 11 rue Turgot, 75009 Paris, France Tel: +3 14 87 81 282 Fax: +33 14 28 52 711 E-mail: biml@oiml.org web site: http://www.oiml.org
- Southern African Development Community Legal Metrology Cooperation Forum (SADCMEL), SADCMEL Secretariat c/o South African Bureau of Standards Tel: +27 12 428 7001 Fax: +27 12 428 6116 E-mail: beardbe@sabs.co.za web site: http://www.sadc-sqam.org/regionalsqam/sadcmel

- The Inter-American Metrology System (SIM), SIM Secretariat, Instituto Nacional de Metrologia, Normalizaçao e Qualidade Industrial, Brazil Tel: +55 21 2563 2817 Fax: +55 21 2502 6542 E- mail : sim@inmetro.gov.br web site: http://www.sim-metrologia.org.br

6. REFERENCES

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[5] ISO: Guide to the Expression of Uncertainty in Measurement, First edition 1995, ISBN 92-67-10188-9.

[6] ISO/IEC 17025, General requirements for the competence of testing and calibration laboratories, 1999

Appendix 1 - Regional Metrology Organisations