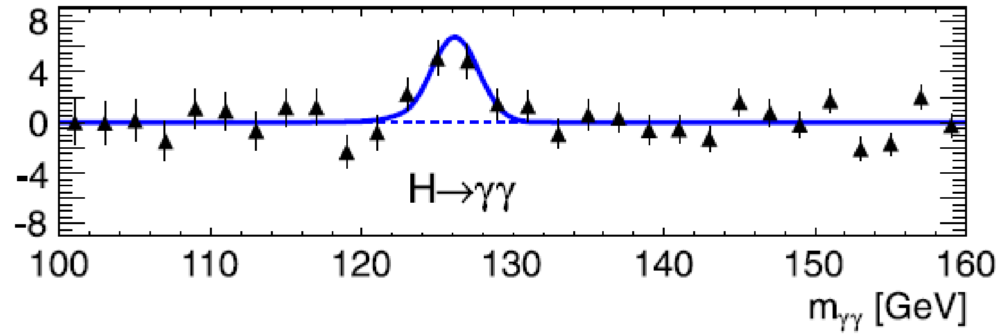
EP122
Measurement Techniques and Calibration

Topic 7

Metrology



http://www.gantep.edu.tr/~bingul/ep122

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May 2016

Introduction

The slides are prepared by using:

“Metrology – in short” 3rd edition (July 2008)

“Kısaca Metroloji” 2nd edition (Temmuz 2008)

You can downlad the original documents from the course web page at:

http://www1.gantep.edu.tr/~bingul/ep122/docs/metrology_inshort_3rd.pdf

http://www1.gantep.edu.tr/~bingul/ep122/docs/kisaca_metroloji_2nd.pdf

Metrology

Metrology is the science of measurement

- People were measuring in history
  time (using moon, sandglass) length, mass, ...

- Today, Metrology is natural and vital part of our everyday life

- Science is completely dependent on measurement

Metrology covers 3 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.

Categories of Metrology

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

1. **Scientific metrology** deals with the organization 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, in production and testing processes, for ensuring quality of life for citizens and for academic research.

3. **Legal metrology** is concerned with measurements where these influence the transparency of economic transactions, particularly where there is a requirement for legal verification of the measuring instrument.

Measurement Standards

A measurement standard 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.

SI Name	Symbol	SI Definition
Meter	m	*The length* of the path travelled by light in vacuum during a time interval of 1/299 792 458 of a second.
Kilogram	kg	*The mass* of the international prototype of the kilogram
Second	s	*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 cesium 133 atom.
Ampere	A	The constant *electric current* which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed 1 metre apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per metre of length.
Kelvin	K	The fraction 1/273.16 of the *thermodynamic temperature* of the triple point of water.
Mole	mol	*The amount of substance* of a system which contains as many elementary entities as there are atoms in 0.012 kilogram of carbon 12 atom.
Candela	cd	*The luminous intensity* in a given direction, of a light source that emits monochromatic radiation of frequency 540×10^{12} Hz and that has a radiant intensity in that direction of 1/683 watt per steradian.

Subject Fields

Scientific metrology is divided into 9 technical subject fields by BIPM:

1. Acoustics,
2. Amount of substance
3. Electricity and Magnetism
4. Ionising radiation and radioactivity
5. Length
6. Mass
7. Photometry and Radiometry
8. Thermometry,
9. Time and Frequency

Some of them will be discussed in the next slides

SUBJECT FIELD	SUBFIELD	IMPORTANT MEASUREMENT STANDARDS
MASS AND RELATED QUANTITIES	Mass measurement	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, capacitance manometers, ionisation gauges
	Volume and density Viscosity	Glass areometers, laboratory glassware, vibration densimeters, glass capillary viscometers, rotation viscometers,

SUBJECT FIELD	SUBFIELD	IMPORTANT MEASUREMENT STANDARDS
ELECTRICITY AND MAGNETISM	DC electricity	Cryogenic 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, calorimeters, bolometers
	High current and high voltage	Measurement transformers of current and voltage, reference high voltage sources

SUBJECT FIELD	SUBFIELD	IMPORTANT MEASUREMENT STANDARDS
LENGTH	Wavelengths and interferometry	Stabilized 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, geodetic length measuring tools
	Angular measurements	Autocollimators, rotary tables, angle gauges, polygons, levels
	Form	Straightness, flatness, parallelism, squares, roundness standards, cylinder standards
	Surface Quality	Step height and groove standards, roughness standards, roughness measurement equipment

SUBJECT FIELD	SUBFIELD	IMPORTANT MEASUREMENT STANDARDS
TIME AND FREQUENCY	Time measurement	Caesium atomic clock, time interval equipment
	Frequency	Atomic clock and fountain, quartz oscillators, lasers, electronic counters and synthesisers, optical combs
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

Traceability & Calibration

Traceability

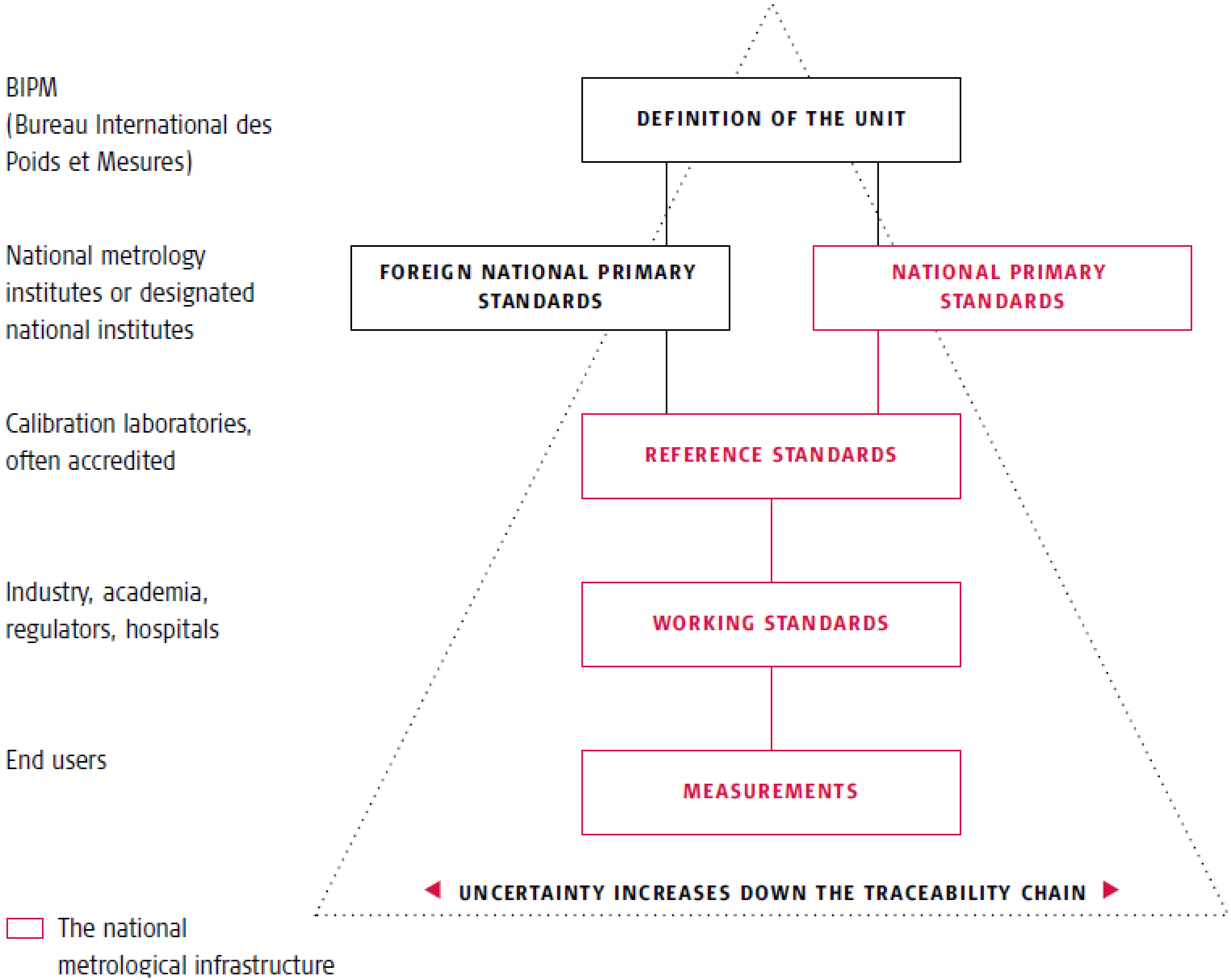
is an unbroken chain of comparisons, all having stated uncertainties. This ensures that a measurement result or the value of a standard is related to references at the higher levels, ending at the primary standard.

Calibration

is the comparison of measurements.

Calibration determines the performance characteristics of an instrument. *It is usually 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.*

The Traceability Chain



Uncertainty

All measurements are subject to error = 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.

- A measurement result is reported in a certificate on the form

$$Y = y \pm U$$

  the uncertainty U is given with no more than **two significant digits** and y is correspondingly rounded to the same number of digits.

Example

Resistance measurement result:
R = (1 000 053 ± 0.000 081) Ω,
Coverage factor k = 2 (95% level of confidence)

GUM: Guide to the expression of uncertainty in measurement

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 with the coverage factor k.
5) State the measurement result on the form
$Y = y \pm U$