[ME 472]

Engineering Metrology & Quality Control

[CHAPTER 1]

Introduction to Measurement & Units

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Metrology:

- Comes from Greek word **"metron (measure)"** and **"–logy"**
- Refers to **science of measurement**, including all theoretical and practical aspects of measurement.

Measurement:

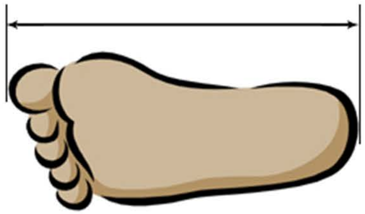
- Refers to the procedure of **comparing an unknown quantity (measurand) to a known standard** by means of consistent system of units.
- Provides **numerical value of quantity** within limits of accuracy and precision.
- Measurements can be categorized as:
  - **Macro-Level:** dimensions (length, angle, etc.), dimensional tolerances, form measurements
  - **Meso-Level:** surface waviness, tolerances of geometric shapes (flatness, roundness, etc.)
  - **Micro-Level:** surface roughness

Inspection:

- Refers to the procedure of **checking the part characteristics (e.g. size, shape, appearance, etc.)** whether they conform to design specification.
- Many inspection procedures rely on **measurement techniques** while others use **ga(u)ging methods** (simply based on whether the part passes or fails the inspection).

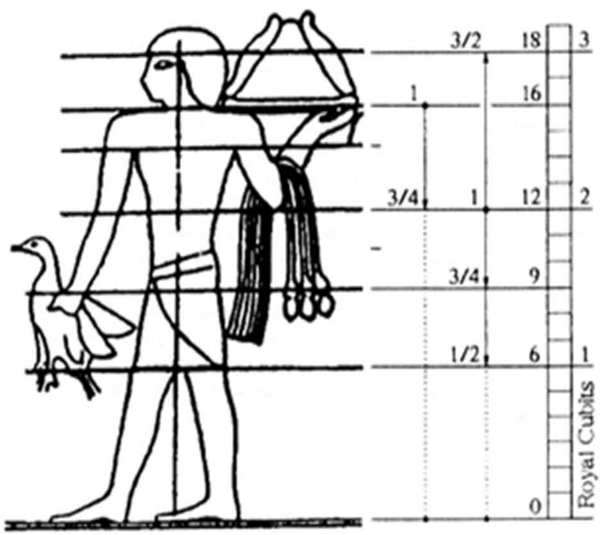
Measurement & Mathematics

- Measurement constitutes first steps towards mathematics.
- In other words, associating numbers with physical objects.

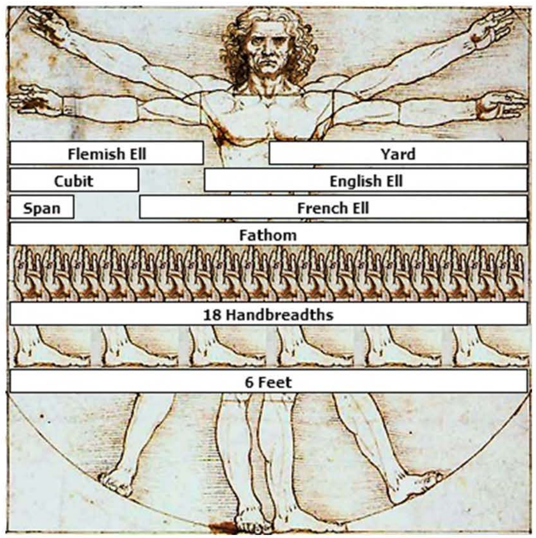


Foot for Length

Seeds & Beans for Weight



Length Fractions on Ancient Man



Vitruvian Man (Leonardo Da Vinci)

Historic Developments in Units

Egyptians (around 5000 B.C.)

↓

Babylonians (around 2000 B.C.)

↓

Harappans (around 1700 B.C.)

↓

Romans & Greek (around 50 B.C.)

↓

British (10^{th} Century)

↓

European (16^{th} Century)

Anthropic Measurements & Units

Digit : breadth of forefinger (Egyptians)

Inch : breadth of thumb

Palm : breadth of four fingers

Span : tip of thumb to tip of little finger (hand spread)

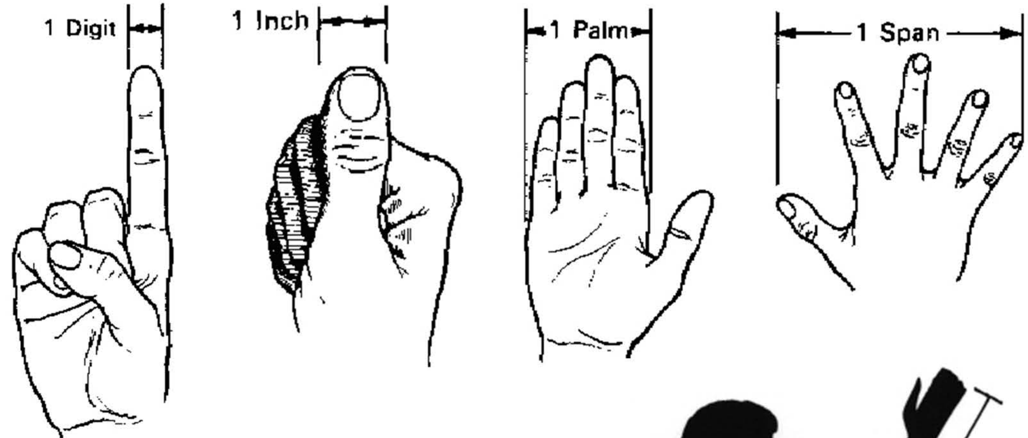
Cubit : elbow to tip of middle finger (Egyptians)

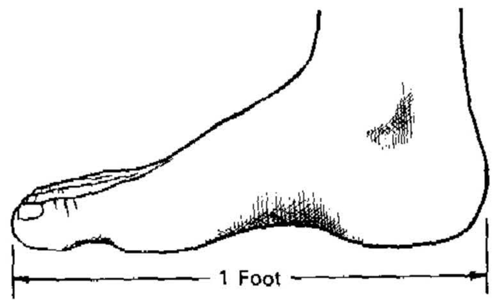
Foot : length of man's foot

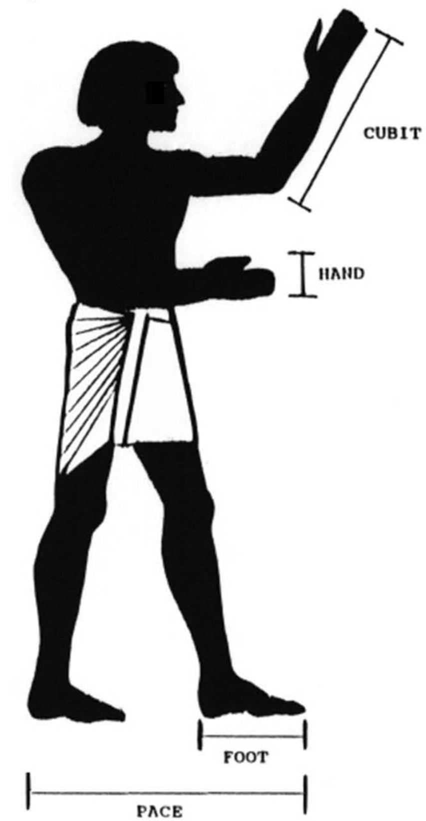
Yard : tip of nose to end of thumb (King Henry I)

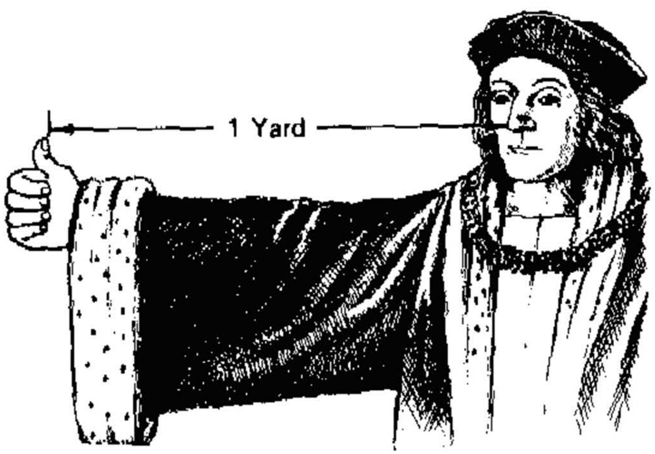
Mile : 5000 Roman feet

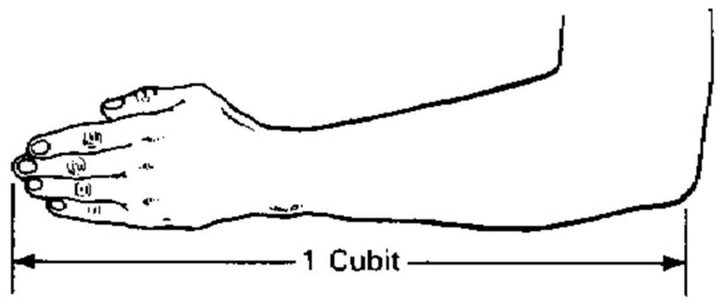
Pace : a full stride (Romans)











Problems & Difficulties with Anthropic Units

Fractions for Smaller Objects

- Fractions based on **a digit**:
  - 28 digits in a cubit
  - 4 digits in a palm
  - 5 digits in a hand
  - 12 digits (3 palms) in a small span
  - 14 digits (or a half cubit) in a large span
  - and so on...
- Then, the problem is:
  Measure something **smaller than a digit**?

Dependence on Human Body

- Units changing **from person to person**!

So, there was need for **consistent system of units**

Establishment of Metric System & Foundation of BIPM

1670 **Gabriel Moulton** (French mathematician) proposed a measurement system based on physical quantities of nature (not on human anatomy).

1790 **The French Academy of Science** recommended the adoption of a system with unit of length (i.e. **metre**), which is equal to one ten-millionth of the distance on a meridian between earth's North Pole and equator.

1870 French conference was set up to **work out standards for a unified metric system**.

1875 (May 20) **The Treaty of Meter (The Meter Convention)** signed by **17 nations** in Paris (including Ottoman Empire).
This had established a permanent body with the authority to set standards:

BIPM - Bureau International des Poids et Mesures *(The International Bureau of Weights and Measures)*

Seal of BIPM

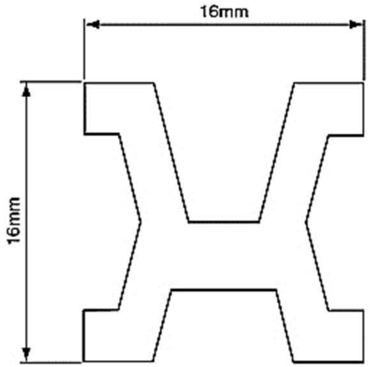
To date of **8 Feb 2022**:
63 Member States & **40** Associate States
https://www.bipm.org

Bureau
International des
Poids et
Mesures

Official Logo of BIPM

International Prototype for "Metre"

- Used as the standard **from 1889 to 1960**.
- Being kept at **BIPM** near Paris.
- Made of special alloy **Pt-10Ir** (90% platinum & 10% iridium by mass) having **Tresca Section** (by French engineer Henri Tresca) in order to **minimize the effects of torsional strain**.



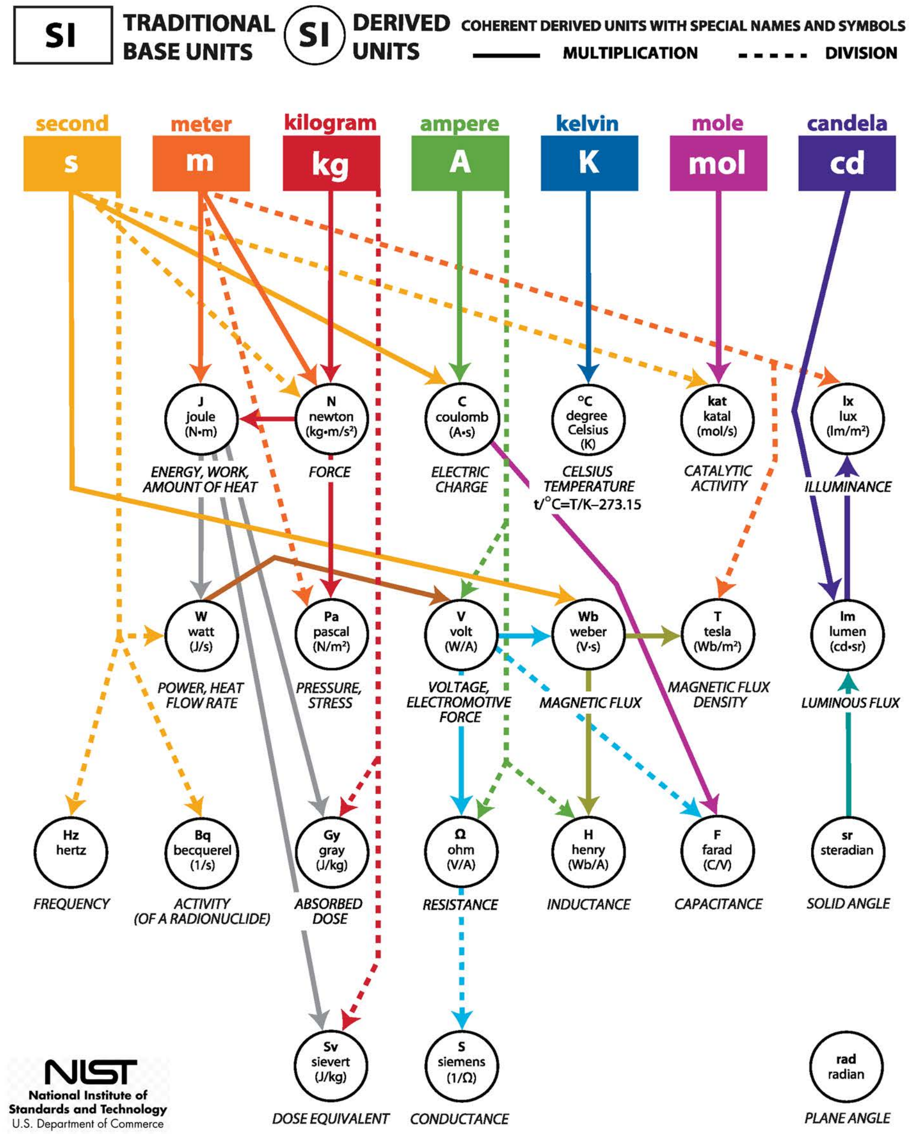
International Prototype for "Kilogram"

- There are two prototypes:
  - **BIPM:** made of **Pt-10Ir** having shape of **right-circular cylinder** (equal height & diameter of 39.17 mm) to **minimize the surface area**.
  - **NIST:** The same alloy and shape, weighing **0.999 999 961 kg of the one at BIPM**.

SI System – Base Units

time	The **second**, symbol s, is the SI unit of time. It is defined by taking the fixed numerical value of the caesium frequency $\Delta\nu_{Cs}$, the unperturbed ground-state hyperfine transition frequency of the caesium 133 atom, to be 9 192 631 770 when expressed in the unit Hz, which is equal to s^{-1}.
length	The **metre**, symbol m, is the SI unit of length. It is defined by taking the fixed numerical value of the speed of light in vacuum *c* to be 299 792 458 when expressed in the unit m s^{-1}, where the second is defined in terms of the caesium frequency $\Delta\nu_{Cs}$.
mass	The **kilogram**, symbol kg, is the SI unit of mass. It is defined by taking the fixed numerical value of the Planck constant *h* to be 6.626 070 15 $\times 10^{-34}$ when expressed in the unit J s, which is equal to kg m^2 s^{-1}, where the metre and the second are defined in terms of *c* and $\Delta\nu_{Cs}$.
electric current	The **ampere**, symbol A, is the SI unit of electric current. It is defined by taking the fixed numerical value of the elementary charge *e* to be 1.602 176 634 $\times 10^{-19}$ when expressed in the unit C, which is equal to A s, where the second is defined in terms of $\Delta\nu_{Cs}$.
thermodynamic temperature	The **kelvin**, symbol K, is the SI unit of thermodynamic temperature. It is defined by taking the fixed numerical value of the Boltzmann constant *k* to be 1.380 649 $\times 10^{-23}$ when expressed in the unit J K^{-1}, which is equal to kg m^2 s^{-2} K^{-1}, where the kilogram, metre and second are defined in terms of *h*, *c* and $\Delta\nu_{Cs}$.
amount of substance	The **mole**, symbol mol, is the SI unit of amount of substance. One mole contains exactly 6.022 140 76 $\times 10^{23}$ elementary entities. This number is the fixed numerical value of the Avogadro constant, N_A, when expressed in the unit mol^{-1} and is called the Avogadro number. The amount of substance, symbol *n*, of a system is a measure of the number of specified elementary entities. An elementary entity may be an atom, a molecule, an ion, an electron, any other particle or specified group of particles.
luminous intensity	The **candela**, symbol cd, is the SI unit of luminous intensity in a given direction. It is defined by taking the fixed numerical value of the luminous efficacy of monochromatic radiation of frequency 540 $\times 10^{12}$ Hz, K_{cd}, to be 683 when expressed in the unit lm W^{-1}, which is equal to cd sr W^{-1}, or cd sr kg^{-1} m^{-2} s^3, where the kilogram, metre and second are defined in terms of *h*, *c* and $\Delta\nu_{Cs}$.

SI System – Derived Units

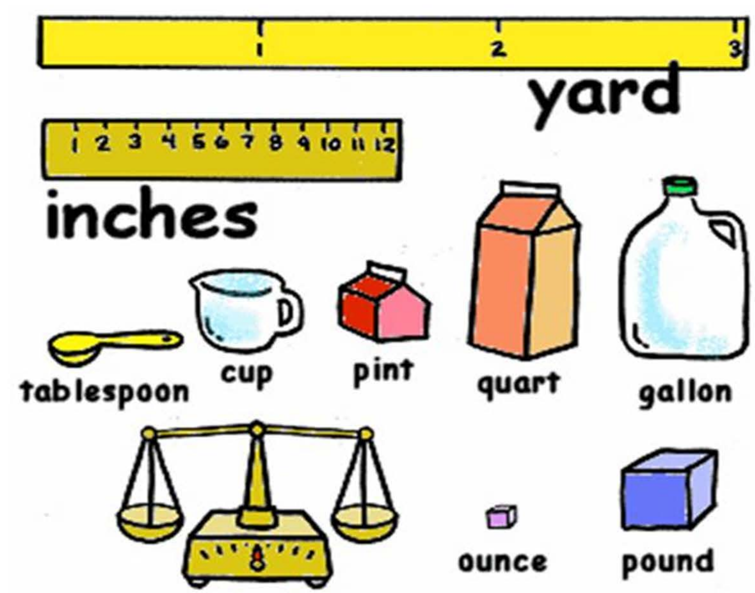


SI (Metric) System

- **International System of Units**
- **Seven base units** (**m**, **kg**, **s**, **A**, **K**, **mol**, **cd**) and other derived units
- Used throughout the world (except US, UK, and few other countries)

Imperial System

- **English (British) System of Units**
- **Different units** for various quantities:
  - **length:** inches / feet / yards / miles
  - **mass:** ounces / pounds / tones
  - **volume:** cups / quarts / gallons / pints



Metric System	Imperial System
Consistently based on decimal numbers	Uses different number systems (base of 3, 8, 12, 14, 16, etc.)
Works well with percentages	Percentages are difficult to work out (try deducting 10% from your weight in stones and pounds!)
Able to deal with small and large quantities (using prefixes based on powers of ten)	Awkward relationship between small and large units (handled with difficult and impractical fractions)
Handles mechanical and electrical quantities	No electrical units (mixing imperial mechanical units and metric electrical units)
Units are the same internationally	Some units differ in version of UK & US (e.g. different pints, gallons, tons, fluid and dry ounces, etc.)
Simple calculations are easy	Simple calculations are needlessly complicated (such as area, energy consumption, and so on)

Adopted from: https://ukma.org.uk/press/reasons-to-metricate/

SI Prefix	Symbol	Multiplier
yotta	Y	10^{24}
zetta	Z	10^{21}
exa	E	10^{18}
peta	P	10^{15}
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
hecto	h	10^{2}
deca	da	10^{1}
-	-	10^{0}
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	u	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}
atto	a	10^{-18}
zepto	z	10^{-21}
yocto	y	10^{-24}

ENGLISH UNITS	ENGLISH EQUIVALENTS	METRIC EQUIVALENTS
1 INCH		about 2-1/2 CENTIMETERS
1 FOOT	12 INCHES	about 30 CENTIMETERS
1 YARD	3 FEET (36 INCHES)	about 1 METER
1 HAND	about 4 INCHES	about 10 CENTIMETERS
1 CUBIT	about 1/2 YARD	about 46 CENTIMETERS
1 BRACCIO	15 to 39 INCHES	about 1/2 to 1 METER
1 FATHOM	6 FEET	about 2 METERS
1 MILE	5,280 FEET	about 1-1/2 KILOMETERS
1 OUNCE		about 28 GRAMS
1 POUND	16 OUNCES	about 1/2 KILOGRAM
1 TEASPOON		about 5 MILLILITERS
1 TABLESPOON	3 TEASPOONS	about 15 MILLILITERS
1 CUP	16 TABLESPOONS	about 250 MILLILITERS
1 QUART	4 CUPS	about 1 LITER
1 GALLON	4 QUARTS	about 4 LITERS

Length Units

m	in	ft	yd	mi
1	39.37008	3.28084	1.093613	0.000621
0.0254	1	0.083333	0.027778	0.000016
0.3048	12	1	0.333333	0.000189
0.9144	36	3	1	0.000568
1609.344	63360	5280	1760	1

Mass Units

kg	tonne	shton	Lton	lb	oz
1	0.001	0.001102	0.000984	2.204586	35.27337
1000	1	1.102293	0.984252	2204.586	35273.37
907.2	0.9072	1	0.892913	2000	32000
1016	1.016	1.119929	1	2239.859	35837.74
0.4536	0.000454	0.0005	0.000446	1	16
0.02835	0.000028	0.000031	0.000028	0.0625	1

Density Units

g/ml	kg/m^3	lb/ft^3	lb/in^3
1	1000	62.42197	0.036127
0.001	1	0.062422	0.000036
0.01602	16.02	1	0.000579
27.68	27680	1727.84	1

High Pressure Units

bar	psi	MPa	kgf/cm^2	mm Hg	atm
1	14.50326	0.1	1.01968	750.0188	0.987167
0.06895	1	0.006895	0.070307	51.71379	0.068065
10	145.03	1	10.197	7500.2	9.8717
0.9807	14.22335	0.09807	1	735.5434	0.968115
0.001333	0.019337	0.000133	0.00136	1	0.001316
1.013	14.69181	0.1013	1.032936	759.769	1

Torque Units

Nm	kgfm	ftlb	inlb
1	0.101972	0.737561	8.850732
9.80665	1	7.233003	86.79603
1.35582	0.138255	1	12
0.112985	0.011521	0.083333	1

Temperature Units

°C	°F	K
1	(°F - 32) x 5/9	K - 273.15
(°C x 9/5) + 32	1	(1.8 x K) - 459.67
(°C + 273.15)	(°F + 459.67) / 1.8	1

National Metrology Institutes (NMI)

- **The main objectives** of NMI are:
  - to build and maintain national standards for measurements
  - to calibrate the measurement standards and devices
- Almost all countries have their own NMI, having relations with **BIPM**.
- National standards are linked to the standards in other countries (or those of **BIPM**) by a process of international comparisons. Therefore, **all measurements are traceable to the national standards**.

Bureau International des Poids et Mesures

NIST National Institute of Standards and Technology U.S. Department of Commerce

The complete list & more info about NMIs can be found at:

https://www.bipm.org/en/cipm-mra/participation

https://www.nist.gov/iaao/national-metrology-laboratories

Metrology Background of Turkey

- The studies related to international measurement system had started on **20 May 1875** when Miralay Hüsnü Bey had signed **The Meter Convention** on behalf of The Ottoman Empire.
- The Ottoman Empire was one of the 17 states who were the founders of Meter Convention, however there were no significant development until **The Law of Weights and Measures (law no: 1781)** was put in act on **26 March 1931**.
- **After the second world war**, need for an integrated system of metrology was felt strongly in Turkey. On the other hand, the volume of the market for calibrations was not large enough to justify a major investment in metrology **until 1980**.
- The Prime Ministry of Turkey asked **TÜBİTAK** (Scientific and Technical Research Council of Turkey) to establish national measurement system in **early 80's**.
- Initial studies began in **1982**, the feasibility study was accepted by all the relevant parties in Turkey.
- **Ulusal Metroloji Enstitüsü** (NMI of Turkey) was founded in **1992** as part of **TÜBİTAK**.

Ulusal Metroloji Enstitüsü (UME)

- Accredited by **TÜRKAK** (Turkish Accreditation Agency) according to **TS EN ISO / IEC 17025**.
- Being a signatory of **CIPM Mutual Recognition Arrangement**, **87 institutes** and **3 international organizations** recognize the calibration certificates and measurement reports issued by UME.
- Associate Member of:
  - **IMEKO** (International Measurement Confederation)
  - **EURAMET** (European Association of National Metrology Institutes)
  - **EURACHEM** (European Association of Analytical Chemistry Laboratories)

Organization Chart of TÜBİTAK UME

- TÜBİTAK Board of Directors
  - TÜBİTAK President
    - TÜBİTAK UME Board of Directors
      - TÜBİTAK UME Director
        - Advisory Board
        - Coordination Board
        - Internal Control Management
        - Quality Board
        - **Deputy Director (Technical)**
          - Atomic Sensors Laboratory
          - Electromagnetic Laboratory
          - High Voltage Laboratory
          - Impedance Laboratory
          - Magnetics Laboratory
          - Medical Metrology Laboratory
          - Optics Laboratory
          - Power and Energy Laboratory
          - Quantum Metrology Laboratory
          - R&D Support & Inf. Systems Laboratory
          - RF & Microwave Laboratory
          - T&F and Wavelength Laboratory
          - Temperature Laboratory
          - Thermodynamics Metrology Laboratory
          - Voltage Laboratory
        - **Deputy Director (Technical)**
          - Acoustics Laboratory
          - Dimensional Laboratory
          - Electrodynamics Laboratory
          - Fluid Flow Laboratory
          - Force Laboratory
          - Mass Laboratory
          - Pressure Laboratory
          - Vacuum Laboratory
          - Volume, Density & Viscosity Laboratory
        - **Deputy Director (Technical)**
          - Bioanalysis Laboratory
          - Electrochemistry Laboratory
          - Gas Metrology Laboratory
          - Inorganic Chemistry Laboratory
          - Organic Chemistry Laboratory
          - Reference Materials Laboratory
        - **Deputy Director (Administrative)**
          - Accounting Dept.
          - Budget Planning & Reporting Dept.
          - Building Maintenance & Opns. Dept.
          - Documentation, Archives & Library Dept.
          - Human Resources Dept.
          - Institutional Development Dept.
          - Institutional Communications Dept.
          - International Relations Dept.
          - Inventory & Stock Dept.
          - Logistics & Social Services Dept.
          - Procurement Dept.
          - Security Dept.
          - Occupational Health & Safety Dept.

More info about TÜBİTAK UME can be found at:

https://www.ume.tubitak.gov.tr/en