CHAPTER 2

STANDARD
Chapter 2 – Standards

1. Classification of standards

2. Types of standards
   - i.e. time/frequency
   - Length
   - electrical (A, C, I)

3. Temperature standard
Standards

• Basically, measurement is an act of a quantitative comparison between a predefined standards and the unknown magnitude of a physical quantity.

• In order that the results are meaningful, the following two requirements must be met in the act of measurement:
  1. The standard that is used for comparison must be well-established, highly accurate and reproducible;
  2. The measurement devices and the calibration procedures adopted in the act of measurement must have proven reliability
Standards of Measurement

• Defined as the *physical representation* of the *unit of measurement*.

  • Chosen with reference to an arbitrary material standard or to a phenomenon that includes physical and atomic constant

  • Example – SI unit of mass namely kilogram, was originally defined as the mass of cubic decimeter of water at its temperature of maximum density i.e. at 4°C
Advantages of SI Systems

1. It is a metric system
2. It is more comprehensive - it defines the units of both primary fundamental as well as auxiliary fundamental quantities.
3. It gives 7 basic units of mass, length, time, temperature, electrical current, luminous and amount of substance
4. Also defined 2 supplementary units of plane angle (in radian) and solid angle (in steradian)
5. This system standardized the abbreviation of different units for complete uniformity and consistency
Classification of Standards

According to their function and type application

- International Standard
- Primary Standard
- Secondary Standard
- Working Standards
Definition of the Unit

The traceability chain

BIPM (Bureau International des Poids et Measures)

National Metrology Institutes or designated national lab

Calibration lab, often accredited

Enterprises

End Users

The national metrological infrastructure

Uncertainty increase down the traceability chain

National Primary Standards

Reference Standards

Industrial Standards

Measurements
International Standard

• Are devices *designed* and *constructed* to specifications of an *international forum*.

• Represents unit of measurement of various physical quantities to the highest possible accuracy that is attainable by use of advanced technique of production and measurement technology.

• Maintained by the BIPM at Sevres, France.
  – Kilogram, wavelength of Kr⁸⁶ orange – red lamp and cesium clock – *mass, length and time*.

• These standards are *not available to an ordinary user* for purpose of day-to-day comparisons and calibration.
Primary Standard

- Devices maintained by organizations/national laboratories in different part of the world or countries
- These devices represent the fundamental and derive quantities and are calibrated independently by absolute measurement.
- The main function of primary standard is to calibrate/check and certify secondary reference standards.
- These standards are not easily available to an ordinary user of instruments for verification/calibration of working standards.
Secondary Standard

• Basic reference standards *employed by industrial measurement laboratories*.
• These standards *maintained by concerned laboratory*.
• The **main function** - *maintenance and periodic calibration* of secondary standards *against primary standards* of the national standards laboratory/organization.
• These standards are *freely available to the ordinary user* of instruments for checking and calibrations of working standards.
Working Standards

- **High-accuracy devices** that **commercially available** and are **duly checked and certified against** either the primary or secondary standards.

- Example:- used for calibrating laboratory instrument e.g. LWI in IVAT is used for carrying out comparison measurements or for checking the quality (range of accuracy) for industrial products.
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   - Length, electrical (A, C, I)
Types of Standards: MASS

• The standard for mass is the International Prototype Kilogram, which is a platinum–iridium cylinder kept at the International Bureau of Weights and Measures in France.

• The kilogram was originally defined as the mass of one liter of pure water at a temperature of 3.98 degrees Celsius and standard atmospheric pressure.
This definition was hard to realize accurately, partially because the density of water depends ever-so-slightly on the pressure, and pressure units include mass as a factor, introducing a circular dependency in the definition of the kilogram.
• To avoid these problems, the *kilogram was redefined* as precisely the mass of a particular standard mass created to approximate the original definition.

• Since 1889, the SI system defines the unit to be equal to the mass of the international prototype of the kilogram, which is made from *an alloy of platinum and iridium of 39 mm height and diameter*, and is kept at the Bureau International des Poids et Mesures (International Bureau of Weights and Measures).

• Official copies of the prototype kilogram are made available as national prototypes, which are compared to the Paris prototype ("Le Grand Kilo") roughly every 10 years. The international prototype kilogram was made in the 1880s.
• The international prototype, made of platinum-iridium, which is kept at the BIPM under conditions specified by the 1st CGPM in 1889
Time/frequency

- 60 seconds = 1 minute
- 3 600 seconds = 1 hour
- 86.4 kiloseconds (86 400 seconds) = 60 seconds x 60 minutes x 24 hours = 1 day (in the SI sense)
• The *factor of 60* may have been influenced by the Babylonians who used factors of 60 in their counting system.

• The *hour* had previously been defined by the Egyptians in *terms of the rotation of the Earth as 1/24 of a mean solar day*.

• This made the *second* 1/86,400 of a mean solar day.

• In 1956 the *second* was defined *in terms of the period of revolution of the Earth around the Sun for a particular epoch*, because by then it had become recognized that the Earth's rotation on its own axis was not sufficiently uniform as a standard of time.
The Earth's motion was described in *Newcomb's Tables of the Sun*, which provides a formula for the motion of the Sun at the epoch 1900 based on astronomical observations made during the eighteenth and nineteenth centuries. The second thus defined is the fraction \(1/31,556,925.9747\) of the tropical year for 1900 January 0 at 12 hours ephemeris time.

Following several years of work, two astronomers at the United States Naval Observatory (USNO) and two astronomers at the National Physical Laboratory (Teddington, England) determined the relationship between the hyperfine transition frequency of the cesium atom and the ephemeris second.
• Using a common-view measurement method based on the received signals from radio station WWV, they determined the orbital motion of the Moon about the Earth, from which the apparent motion of the Sun could be inferred, in terms of time as measured by an atomic clock.

• As a result, in 1967 the Thirteenth General Conference on Weights and Measures defined the second of atomic time in the International System of Units (SI) as 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 ground state is defined at zero magnetic fields. The \textit{second} thus defined is \textit{equivalent to the ephemeris second}.

• The \textit{definition of the second} was later \textit{refined} at the 1997 meeting of the BIPM to include the statement. This definition \textit{refers to a cesium atom at rest at a temperature of 0 K}. 
Length

• In the past, standards of length included king’s foot, king’s forearm (for 1 yard), etc.

• The *meter* originally intended to be *one ten-millionth of the earth quadrant*.

• In 1889 the first general conference on weights and measures defined meter as length of the International Prototype Meter, *the distances between two finely scribed lines of platinum-iridium bar* when subject to certain specified conditions.
• International Prototype Meter *standard bar made of platinum-iridium*. This was the standard until 1960, when the new SI system used a *krypton-spectrum measurement* as the base. In 1983 the *current meter* was defined by a *relationship to the speed of light in a vacuum* which defines as “*the length of the path traveled by light in a vacuum during a time of 1/299,792,458 of a second***"
Electrical

- **Absolute Ampere**
  - 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 meter apart in vacuum, would produce between these conductors a force equal to $2 \times 10^{-7}$ Newton per meter of length → further explanation

- Absolute ampere measurements, for example, involve the use of a weighing-balance scheme that measures the force between a set of fixed coils and a moving coil [http://library.thinkquest.org/C001429/electricity/electricity28.htm]
• Because it is a base unit, the definition of the ampere is not tied to any other electrical unit. The definition for the ampere is *equivalent to fixing a value of the permeability of vacuum to* $\mu_0 = 4\pi \times 10^{-7}\text{ H/m}$. Prior to 1948, the so-called "international ampere" was used, defined in terms of the electrolytic deposition rate of silver. The older unit is equal to 0.999 85 A.

• The ampere is most accurately realized using an ampere balance, but is in practice maintained via Ohm's Law from the units of voltage and resistance, the volt and the ohm, since the latter two can be tied to physical phenomena that are relatively easy to reproduce, the Josephson junction and the quantum Hall effect, respectively.
The unit of electric charge, the **coulomb**, is defined *in terms of the ampere*: one coulomb is the amount of electric charge (formerly quantity of electricity) carried in a current of one ampere flowing for one second. Current (electricity), then, is the rate at which charge flows through a wire or surface. **One ampere of current** (I) is equal to a flow of one coulomb of charge (Q) per second of time (t):

\[
I = \frac{Q}{t}
\]
• Since a coulomb is approximately equal to $6.24 \times 10^{18}$ elementary (basic) charges, one ampere is equivalent to $6.24 \times 10^{18}$ elementary charges, such as electrons, moving through a surface in one second.

• More precisely, using the SI definitions for the conventional values of the Josephson and Von Klitzing constants, the ampere can be defined as exactly $6.24150962915265 \times 10^{18}$ elementary charges per second.
Voltage standard

• The volt (symbol: V) is the SI derived unit of electric potential difference. The number of volts is a measure of the strength of an electrical source in the sense of how much power is produced for a given current level. It is named in honor of Alessandro Volta (1745–1827), who invented the voltaic pile, the first chemical battery.
The volt is defined as the *potential difference across a conductor when a current of one ampere dissipates one watt of power*. Hence, it is the base SI representation $m^2 \cdot kg \cdot s^{-3} \cdot A^{-1}$, which can be equally represented as *one joule of energy per coulomb of charge, J/C.*

$$1 \, V = 1 \, W/A = 1 \, m^2 \cdot kg \cdot s^{-3} \cdot A^{-1}$$
Since 1990 the volt is maintained internationally for practical measurement using the *Josephson effect*, where a conventional value is used for the *Josephson constant*, fixed by the 18th General Conference on Weights and Measures as

\[ K_{\text{J-90}} = 0.4835979 \text{ GHz/\mu V}. \]
• The **electrical potential difference** can be thought of as **the ability to move electrical charge through a resistance**. In essence, the **volt measures how much kinetic energy each electron carries**.

• The number of electrons is measured by the charge, in coulombs. Thus the volt is multiplied by the current flow, in amperes which are one coulomb per second, to **yield the total electrical power in the current, in Watts**.

• At a time in physics when the word force was used loosely, the **potential difference was named the electromotive force or emf** - a term which is still used in certain contexts
Voltage Standard based on Josephson Junction

- The **Primary standard** for voltage is based on the **Josephson effect**
- This occurs **across 2 semiconductors separated by a thin insulator**

A Josephson Junction
- When cooled in **liquid helium** the semiconductors become **superconductors** exhibit zero resistance
- The following diagram illustrates the device.
The Josephson Junction

Niobium semiconductor

Niobium semiconductor

Oxidised Aluminium insulator
• The junction is *biased with a DC current*
• The junction is *exposed to high frequency microwave radiation* (GHz)
• A *DC voltage* is produced *across* the junction
• Voltage is *directly proportional* to frequency
• It was discovered that the following *I-V characteristic* was produced
I-V characteristic

Bias
Current

DC Voltage across
• As the bias current was increased the voltage increased in a number of equal steps of constant voltage

• The voltage at a particular step is given by

\[ V_n = \frac{f \cdot n \cdot h}{2e} \]
where:

\[ f = \text{the microwave radiation frequency (Hz)} \]
\[ n = \text{the number of the particular step} \]
\[ e = \text{the fundamental charge on an electron (}1.602 \times 10^{-19} \text{ C)} \]
\[ h = \text{Plank’s Constant (}6.626 \times 10^{-34} \text{ J.s)} \]
• In 1990 the ratio $2e/h$, called the **Josephson Constant** $K_j$, was agreed internationally to be:

$$K_j = 483\ 597.9\ \text{GHz/V}$$

• Note that the output is based on **constants of nature**

• Anywhere in the universe $K_j$ **should be the same**

Thus

$$V_n = \frac{f \cdot n}{K_j}$$
• For example if $f = 75 \text{GHz}$:
  $$V_j = 155.1 \mu \text{V/step}$$
• This is an incredibly small voltage
• Modern systems contain several thousand junctions combined in series
• **Typical Uncertainty** is 0.2 ppb
  – parts per billion
  – 0.2 parts in $1 \times 10^{12}$
Voltage Standard based on Weston Cell

- **The Weston cell**, invented by Edward Weston in 1893, is a *wet-chemical cell* (colloquially: battery) that *produces a highly stable voltage suitable* as a laboratory standard for calibration of voltmeters.

- The original design was a *saturated cadmium cell producing a convenient 1.0183 Volt reference and had the advantage of having a lower temperature coefficient* than the previously used Clark cell. (Reference cells must be applied in such a way that no current is drawn from them.)
• The Weston cell was adopted as the International Standard for EMF in 1911.

• The *temperature coefficient* can be reduced by shifting to an unsaturated design, the predominant type today. However, an unsaturated cell's output decreases by some 80 microvolts per year, which is compensated by periodical calibration against a saturated cell.
Resistance Standard based on Quantum Hall Effect

- To realize the ampere we have created half of the story – the volt
- We now examine the other half – the ohm
- The **primary standard** for resistance is based on the **Hall effect**
• Recall the principle
  – A thin semiconductor bar carries a *DC current*
  – The bar is subjected to a *magnetic field perpendicular* to it
  – A *Voltage develops* across the bar *perpendicular* to the *direction of the current flow*
• This is the *Hall Voltage*
  – The ratio of the Hall Voltage to the DC current is called the *Hall Resistance, \( R_H \) of the bar.*
In 1980 it was discovered that by:

- **cooling** the bar in **liquid helium**  
  - semiconductor becomes a superconductor; and
- **greatly increasing** the magnetic field

- the Hall resistance **increased in discrete steps**

- At each step the resistance **remained extremely constant**

- This effect was called the **Quantum (Quantized) Hall Effect**
QUANTUM HALL EFFECT

Hall Resistance $R_H$

Magnetic Field
The more remarkable discovery was the equation describing $R_H$

$$R_H = \frac{h}{e^2} \cdot n = R_K \cdot n$$

Where:

– $n = \text{the number of the particular step}$
– $e = \text{the fundamental charge on an electron} \ (1.602 \times 10^{-19} \text{ C})$
– $h = \text{Plank’s Constant} \ (6.626 \times 10^{-34} \text{ J.s})$
Since 1990 it was agreed that the value of $R_K$ was:

$$R_K = 25812.807 \pm 0.005\Omega$$

- $R_K$ is called the \textit{Von Klitzing Constant} after the discoverer of the effect.
- Typical uncertainty is $\pm 0.2$ ppm.
- A standard based on universal constants has been realized.
- The standards for the volt and ohm allow us to realize the ampere to about 0.2 ppm.
Capacitive Standard
A capacitor is an *electrical device* that can store energy in the electric field between *a pair of closely spaced conductors* (called *'plates'*). When voltage is applied to the capacitor, electric charges of equal magnitude, but opposite polarity, build up on each plate.

The **farad** (symbol: F) is the SI unit of capacitance. It is named after Michael Faraday.
• Capacitors are used in electrical circuits as energy-storage devices. They can also be used to differentiate between high-frequency and low-frequency signals and this makes them useful in electronic filters.

• A capacitor is occasionally referred to using the older term condenser.
• A capacitor has a value of **one farad** when **one coulomb of stored charge causes a potential difference of one volt across its terminals**. Its equivalent expression in SI base units is:

\[
C = \frac{Q}{V}
\]

\[
F = C \cdot V^{-1} = m^{-2} \cdot kg^{-1} \cdot s^4 \cdot A^2
\]
• The capacitance is proportional to the surface area of the conducting plate and inversely proportional to the distance between the plates. It is also proportional to the permittivity of the dielectric (that is, non-conducting) substance that separates the plates.

• The capacitance of a parallel-plate capacitor is given by:

\[ C \approx \frac{\varepsilon A}{d}; \quad A \gg d^2 \]

• where \( \varepsilon \) is the permittivity of the dielectric, \( A \) is the area of the plates and \( d \) is the spacing between them
When electric charge accumulates on the plates, an electric field is created in the region between the plates that is proportional to the amount of accumulated charge. This electric field creates a potential difference $V = E \cdot d$ between the plates of this simple parallel-plate capacitor.
• Since the farad is a very large unit, values of capacitors are usually in range of microfarads (μF), nanofarads (nF), or picofarads (pF). The picofarad is comically called a "puff" in laboratory usage.

• The millifarad is rarely used in practice, so that a capacitance of $4.7 \times 10^{-3}$ F, for example, is usually written as 4700 μF. Very small capacitance values, such as those used in integrated circuits may also be expressed in femtofarads, one femtofarad being equal to $1 \times 10^{-15}$ F.
Inductance Standard
• Inductance is a measure of the amount of magnetic flux produced for a given electric current.

\[ L = \frac{\Phi}{i} \]

where

– \( L \) is the inductance in henries,
– \( i \) is the current in amperes,
– \( \Phi \) is the magnetic flux in webers
• The symbol L is used for inductance in honour of the physicist Heinrich Lenz. The term inductance was coined by Oliver Heaviside in February 1886. The SI unit of inductance is the *henry* (symbol: H).

• Strictly speaking, the quantity just defined is called *self-inductance*, because the *magnetic field* is created solely by the conductor that *carries the current*. 
• When a conductor is coiled upon itself $N$ number of times around the same axis, the current required to produce a given amount of flux is reduced by a factor of $N$ compared to a single turn of wire. Thus, the inductance of a coil of wire of $N$ turns is given by:

$$L = \frac{\lambda}{i} = N \frac{\Phi}{i}$$

• where $\lambda$ is the total 'flux linkage'.
• Such a coiled conductor is an example of an Inductor.

• The **Henry** (symbol: H) is the SI unit of inductance. It is named after the American scientist Joseph Henry.

• If the *rate of change of current* in a circuit is **one ampere per second** and the *resulting electromotive force is one volt*, then the inductance of the circuit is **one henry**.

\[
1 \text{ H} = \text{Wb/A} = 1 \text{ m}^2\cdot\text{kg}\cdot\text{s}^{-2}\cdot\text{A}^{-2} = 1 \text{ V}\cdot\text{s/A}
\]
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Temperature Standard

- The standard for *temperature* is more *complicated* than for the other base units since it *must be specified over a wide range of values*.

- The standard is known as the International Temperature Scale of 1990 (ITS-90) (Preston–Thomas, 1990).
• The measure of temperature is the thermodynamic temperature, and the unit is the **Kelvin**, defined as \( \frac{1}{273.16} \) of the thermodynamic temperature of the **triple point of water**, that temperature where **solid, liquid, and vapor** phases of **pure water exist together in thermal equilibrium** (balance).

![Temperature Scales](image)

• The standard temperature scale extends from 0.65 K to the **highest temperatures** that can be determined by measuring thermal radiation.
<table>
<thead>
<tr>
<th>Fixed point</th>
<th>Temperature (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triple point of <em>hydrogen</em></td>
<td>13.8033</td>
</tr>
<tr>
<td>Triple point of <em>neon</em></td>
<td>24.5561</td>
</tr>
<tr>
<td>Triple point of <em>oxygen</em></td>
<td>54.3584</td>
</tr>
<tr>
<td>Triple Point of <em>argon</em></td>
<td>83.8058</td>
</tr>
<tr>
<td>*Triple Point of <em>Water</em></td>
<td>273.160</td>
</tr>
<tr>
<td>Freezing point of <em>tin</em></td>
<td>505.078</td>
</tr>
<tr>
<td>Freezing point of <em>silver</em></td>
<td>1234.93</td>
</tr>
<tr>
<td>Freezing point of <em>copper</em></td>
<td>1357.77</td>
</tr>
</tbody>
</table>
Temperature Conversion Formulas (Kelvin)

- **Celsius** [$°C$]  
  \[ °C = (K - 273.15) \]
  \[ °C = (°C + 273.15) \]

- **Fahrenheit** [$°F$]  
  \[ °F = (K \cdot 9/5) - 459.67 \]
  \[ °F = ((°F + 459.67) \cdot 5/9) \]

- **Newton** [$°N$]  
  \[ °N = ((K - 273.15) \cdot 33/100) \]
  \[ °N = (°N \cdot 100/33 + 273.15) \]
• **Rankine** \( ^\circ \text{Ra} \)  = \([\text{K}] \cdot 9/5[\text{K}] \)
  = \( ^\circ \text{Ra} \cdot 5/9 \)

• **Réaumur** \( ^\circ \text{Ré} \)  = \(([\text{K}] - 273.15) \cdot 4/5[\text{K}] \)
  = \( ^\circ \text{Ré} \cdot 5/4 + 273.15 \)

• **Rømer** \( ^\circ \text{Rø} \)  = \(([\text{K}] - 273.15) \cdot 21/40 + 7.5[\text{K}] \)
  = \((^\circ \text{Rø} - 7.5) \cdot 40/21 + 273.15 \)

• **Delisle** \( ^\circ \text{De} \)  = \((373.15 - [\text{K}]) \cdot 3/2[\text{K}] \)
  = 373.15 - \( ^\circ \text{De} \cdot 2/3 \)
Summary

• What is Standard? Standard of measurement? Unit of measurement?
• Advantages of SI unit?
• Classification of Standard...
• Type of standard...mass, time/frequency, length, electrical (current Ohm’s Law), voltage (Josephson Effect & Weston Cell), resistance (Quantum Hall Effect), capacitance & inductance)
• Temperature standard
Appendixes
Absolute

• Part of the names of several electrical units, the absolute ampere, absolute ohm, absolute volt, etc., distinguishing them from the international ampere, etc.

• In the British Association Report of 1863, “absolute” applied to a unit meant “that the measurement, instead of being a simple comparison with an arbitrary quantity of the same kind as that measured, is made by reference to certain fundamental units of another kind treated as postulates.” The word may have been first used in this sense by Gauss in an 1832 paper titled, “Intensitas vis magneticae terristis in mensuram absolutam revocata.”
Electric current is the **time rate of change** or **displacement of electric charge**. One ampere represents the rate of 1 coulomb of charge per second.

\[
1\text{A} = 1\text{C/s}
\]

The ampere is defined first (it is a base unit, along with the meter, the second, and the kilogram), without reference to the quantity of charge. The unit of charge, the **coulomb**, is defined to be the **amount of charge displaced by a one ampere current in the time of one second**.
Ohm’s Law

• **Ohm's law** states that, in an **electrical circuit**, the **current** passing through a conductor, from one terminal point on the conductor to another terminal point on the conductor, is directly **proportional** to the **potential difference** (i.e. **voltage drop** or **voltage**) across the two terminal points and inversely proportional to the resistance of the conductor between the two terminal points.

• For real devices (**resistors**, in particular), this law is usually valid over a large range of values of current and voltage, but exceeding certain limitations may result in losing simple direct proportionality.
• In mathematical terms, this is written as:

\[ V = IR \quad \text{or} \quad I = V/R \]

• where \( I \) is the current, \( V \) is the potential difference, and \( R \) is a constant called the resistance. The potential difference is also known as the voltage drop, and is sometimes denoted by \( E \) or \( U \) instead of \( V \).

• The SI unit of current is the ampere; that of potential difference is the volt; and that of resistance is the ohm, equal to one volt per ampere.
Ohm's law with a **voltage source**

Source and load circuit with **R** resistors

Source and load circuit with **Z** resistors
Source and load circuit with Zs in boxes

Ohm's law with a current source
The Weston Cell

• Chemical details
  – **cathode** - amalgam of cadmium with mercury
  – **anode** - pure mercury
  – **electrolyte** - solution of cadmium sulphate.
Triple Point

• In physics, the **triple point** of a substance is the temperature and **pressure** at which three phases (gas, liquid, and solid) of that substance (material) may coexist in thermodynamic equilibrium.

• For example, the triple point temperature of mercury is at $-38.8344 \degree C$, at a pressure of 0.2 mPa.

• The triple point of water is used to define the Kelvin, the SI base unit of thermodynamic temperature. The **number given for the temperature** of the triple point of water is an **exact definition rather than a measured quantity**.
A typical phase diagram. The **dotted green line** gives the *abnormal/unusual behaviors* of water
The single combination of pressure and temperature at which pure water (liquid), pure ice (solid), and pure water vapour (gas) can coexist in a stable equilibrium occurs at exactly 273.16 Kelvin (0.01 °C) and a pressure of 611.73 pascals (ca. 6.1173 millibars, 0.0060373057 atm).

At that point, it is possible to change all of the substance to ice, water, or vapour by making infinitesimally small changes in pressure and temperature.

Strictly speaking, the surfaces separating the different phases should also be perfectly flat, to avoid the effects of surface tensions.