What is Measurement?

- **Measurement**
  - Measurement (also called metrology) is the science of determining values of physical variables.
  - A method to obtain information regarding the physical values of the variable.
  - Measurement of a given quantity is essentially an act or result of comparison between the quantity (whose magnitude is unknown) and predetermined or predefined standards.
  - Two quantities are compared the result is expressed in numerical values.

- **Instrumentation**
  - Devices used in measurement system
Physical Variables

- Temperature
- Pressure
- Light intensity
- Displacement
- Speed
- Level
- Flow-rate etc

Why Do We Measure?

In the case of process industries and industrial manufacturing
- To improve the quality of the product
- To improve the efficiency of production
- To maintain the proper operation.
History of Measurement

Units of measurement based on the human body

Diagram of Yup’ik (Alaska Native) units of length

Relief carving of Ancient Greek measurement using hand span and foot

Diagram of Egyptian definitions of cubit and palm

The needs for Measurement

With trade and taxation came the need for standardized units

Standard weights for measuring gold dust used by the Asante of Ghana

Standardized weights from the Indus river valley

A bronze ruler from the Han dynasty in China
**The needs for Measurement**

The measure for the weight of the precious stones, such as diamond, carat is used. Carat was the weight of four carob (Keçiboynuzu) beans. Today carat is standardized as 0.2 gr.

*Diamonds are forever!*  
*Carob Beans*

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**Metric System - 1**

*The first improved unit was the unit of length (the meter) defined as $10^{-7}$ times the polar quadrant of the earth.*

*In 19th century, a platinum bar made to this length was established as the standard of length. However this was shorter than the previous meter so that he circumference of the Earth through the poles is then 40,007,863 m.*

*In 1960, a standard meter was redefined in terms of $1.65076373 \times 10^6$ wavelength of the radiation from krypton-86 in space.*

*Since 1983, the meter has been defined as the distance that light travels in 1/299,792,458th of a second*
The Canadian Standard Kilogram.

The kilogram is the only unit in the metric system defined by an actual object.

A cube of water with sides each 1 cm has a mass of 1 gram.

<table>
<thead>
<tr>
<th>PREFIX</th>
<th>SYMBOL</th>
<th>BASE UNIT MULTIPLIED BY*</th>
<th>EXAMPLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>mega</td>
<td>M</td>
<td>$1,000,000 = 10^6$</td>
<td>1 megameter (Mm) = $10^6$ m</td>
</tr>
<tr>
<td>kilo</td>
<td>k</td>
<td>$1000 = 10^3$</td>
<td>1 kilogram (kg) = $10^3$ g</td>
</tr>
<tr>
<td>hecto</td>
<td>h</td>
<td>$100 = 10^2$</td>
<td>1 hectogram (hg) = 100 g</td>
</tr>
<tr>
<td>deka</td>
<td>da</td>
<td>$10 = 10^1$</td>
<td>1 dekaliter (daL) = 10 L</td>
</tr>
<tr>
<td>deci</td>
<td>d</td>
<td>$0.1 = 10^{-1}$</td>
<td>1 deciliter (dL) = 0.1 L</td>
</tr>
<tr>
<td>centi</td>
<td>c</td>
<td>$0.01 = 10^{-2}$</td>
<td>1 centimeter (cm) = 0.01 cm</td>
</tr>
<tr>
<td>milli</td>
<td>m</td>
<td>$0.001 = 10^{-3}$</td>
<td>1 milligram (mg) = 0.001 g</td>
</tr>
<tr>
<td>micro</td>
<td>$\mu$</td>
<td>$0.000 001 = 10^{-6}$</td>
<td>1 micrometer ((\mu)m) = $10^{-6}$ m</td>
</tr>
<tr>
<td>nano</td>
<td>n</td>
<td>$0.000 000 001 = 10^{-9}$</td>
<td>1 nanogram (ng) = $10^{-9}$ g</td>
</tr>
<tr>
<td>pico</td>
<td>p</td>
<td>$0.000 000 000 001 = 10^{-12}$</td>
<td>1 picogram (pg) = $10^{-12}$ g</td>
</tr>
<tr>
<td>femto</td>
<td>f</td>
<td>$0.000 000 000 000 001 = 10^{-15}$</td>
<td>1 femtogram = $10^{-15}$ g</td>
</tr>
</tbody>
</table>
Metric System - 4

SI Units: Systemes Internationales d’Unites

Two different units are defined:
- Fundamental Units
- Derived Units

Fundamental Units

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Standart Unit</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>meter</td>
<td>m</td>
</tr>
<tr>
<td>Mass</td>
<td>kilogram</td>
<td>kg</td>
</tr>
<tr>
<td>Time</td>
<td>second</td>
<td>s</td>
</tr>
<tr>
<td>Electric current</td>
<td>ampere</td>
<td>A</td>
</tr>
<tr>
<td>Temperature</td>
<td>kelvin</td>
<td>K</td>
</tr>
<tr>
<td>Luminous Intensity</td>
<td>candela</td>
<td>cd</td>
</tr>
<tr>
<td>Matter</td>
<td>mole</td>
<td>Mol</td>
</tr>
<tr>
<td>Plane Angle*</td>
<td>radian</td>
<td>rad</td>
</tr>
<tr>
<td>Solid Angle*</td>
<td>steradian</td>
<td>sr</td>
</tr>
</tbody>
</table>

* Additional units
### Derived Units

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Standart Unit</th>
<th>Symbol</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
<td>square meter</td>
<td>m²</td>
<td></td>
</tr>
<tr>
<td>Volume</td>
<td>cubic meter</td>
<td>kg</td>
<td></td>
</tr>
<tr>
<td>Velocity</td>
<td>Meter per second</td>
<td>m/s</td>
<td></td>
</tr>
<tr>
<td>Density</td>
<td>Kilogram per cubic meter</td>
<td>kg/m³</td>
<td></td>
</tr>
<tr>
<td>Force</td>
<td>newton</td>
<td>N</td>
<td>kg-m/s²</td>
</tr>
<tr>
<td>Work; energy</td>
<td>joule</td>
<td>J</td>
<td>N-m</td>
</tr>
<tr>
<td>Power</td>
<td>watt</td>
<td>W</td>
<td>J/s</td>
</tr>
<tr>
<td>Voltage; e.m.f.; pot. diff.</td>
<td>volt</td>
<td>V</td>
<td>W/A</td>
</tr>
<tr>
<td>Resistance</td>
<td>ohm</td>
<td>Ω</td>
<td>V/A</td>
</tr>
<tr>
<td>Frequency</td>
<td>Hertz</td>
<td>Hz</td>
<td>s⁻¹</td>
</tr>
</tbody>
</table>

### Examples of Standard Bodies

- International Organization for Standardization (ISO)
- International Electrotechnical Commission (IEC)
- American National Standards Institute (ANSI)
- Standards Council of Canada (SCC)
- British Standards (BS)
- Institute of Turkish Standards (TSE)
Standards

1. International standards:
   - Defined by international agreements
2. Primary standards:
   - Maintained at institutions around the world
   - Main function is checking accuracy of secondary standards

Elements of a Simple Closed Loop Control System
**Real World Connections**

- **real world**
- **sensor**
- **actuator**
- **intelligent feedback system**

**Terminology - 1**

- **Measured**: Physical quantity being measured.
- **Calibration**: Implies that there is a numeric relationship throughout the whole instrumentation system and that it is directly related to an approved national or international standard.
- **Test instrumentation**: It is a branch of instrumentation and most closely associated with the task of gathering data during various development phases encountered in engineering, e.g. flight test instrumentation for testing and approving aircraft.
Terminology - 2

- Transducer: A device that converts one form of energy to another.
- Electronic transducer: It has an input or output that is electrical in nature (e.g., voltage, current or resistance).
- Sensor: Electronic transducer that converts physical quantity into an electrical signal.
- Actuator: Electronic transducer that converts electrical energy into mechanical energy.

Transduction

Signal domains:
- Magnetic (Ma),
- Mechanical (Me),
- Thermal (Th),
- Optical (Op),
- Chemical (Ch) and
- Electrical (El).
**Transduction Matrix**

Transduction matrix:

\[
\begin{pmatrix}
M_a \\
M_e \\
T_h \\
O_p \\
C_h \\
E_l
\end{pmatrix} = \begin{pmatrix}
t_{m_a,m_a} & t_{m_a,m_e} & t_{m_a,t_h} & t_{m_a,o_p} & t_{m_a,c_h} & t_{m_a,e_l} \\
t_{m_e,m_a} & t_{m_e,m_e} & t_{m_e,t_h} & t_{m_e,o_p} & t_{m_e,c_h} & t_{m_e,e_l} \\
t_{t_h,m_a} & t_{t_h,m_e} & t_{t_h,t_h} & t_{t_h,o_p} & t_{t_h,c_h} & t_{t_h,e_l} \\
t_{o_p,m_a} & t_{o_p,m_e} & t_{o_p,t_h} & t_{o_p,o_p} & t_{o_p,c_h} & t_{o_p,e_l} \\
t_{c_h,m_a} & t_{c_h,m_e} & t_{c_h,t_h} & t_{c_h,o_p} & t_{c_h,c_h} & t_{c_h,e_l} \\
t_{e_l,m_a} & t_{e_l,m_e} & t_{e_l,t_h} & t_{e_l,o_p} & t_{e_l,c_h} & t_{e_l,e_l}
\end{pmatrix} \quad + \quad \begin{pmatrix}
M_{a,0} \\
M_{e,0} \\
T_{h,0} \\
O_{p,0} \\
C_{h,0} \\
E_{l,0}
\end{pmatrix}
\]

**Sensor**

- A device that converts information from one energy domain into the **electrical** domain
- Where it can be easily (digitally) processed and stored
Elements of a Measuring Instrument

- Measured variable (measurand)
- Sensor
- Variable conversion element
- Signal processing
- Output measurement
- Output display/recording
- Use of measurement at remote point
- Signal presentation or recording
- Signal transmission