# Lecture No. 3

Electrical Measurement and Instrumentation

# Standards of Measurement

- **CLASSIFICATION OF STANDARDS**
- A standard of measurements is a physical representation of a unit of measurement
- A unit is realized by reference to an arbitrary material standard or to natural phenomena including physical and atomic constants.
- For example, the fundamental unit of mass in the international system (SI) is the kilogram,
  - defined as the mass of a cubic decimeter of water as its temperature of maximum density of 4°C
- This unit is represented by a material standard;
  - the mass of the International Prototype Kilogram, consisting of a platinum-iridium alloy cylinder.
  - preserved at the International Bureau of Weights and Measures at Sèvres, near Paris

# Types of Standards of Measurements

- Various Types of categories of Standards include:
- *International standards*
- *Primary standards*
- *Secondary standards*
- *Working standards*

# International standards

- The international standards are defined by international agreements.
- Represent certain units of measurement to the closest possible accuracy that production and measurement technology allows.
- Standards are periodically evaluated and checked by absolute measurements in terms of the fundamental units (see Table 2-2).
- They are maintained at the International Bureau of Weights and Measures
  - not available to the ordinary user of measuring instruments, for purposes of comparison or calibration.

# Primary standards

- The primary (basic) standards are maintained by national standards laboratories in different parts of the world.
- The National Bureau of Standards (NBS) in Washington is responsible for maintenance of the primary standards in North America.
- Other national laboratories include the National Physical Laboratory (NPL) in Great Britain
- The Physikalisch-Technische Reichsanstalt in Germany.

# Primary standards……..

- These standards represent the fundamental units and some of the derived mechanical and electrical units,
  - are independently calibrated by absolute measurements at each of the national laboratories.
- The results of these measurements are compared against each other, leading to a world average figure for the primary standard.
- Primary standards are not available for use outside the national laboratories.
- One of the main functions of primary standards is the verification and calibration of secondary standards.

# Secondary standards

- These are basic reference standards used in industrial measurement laboratories.
- These are maintained by the particular involved industry and are checked locally against other reference standards in the area.
- maintenance and calibration responsibilities of secondary standards rests entirely with the industrial laboratory itself.
- They are generally sent to the national standards laboratories on a periodic basis for calibration and comparison against the primary standards.
- They are then returned to the industrial user with a certification of their measured value in terms of the primary standard.

# Working standards

- Working standards are the principal tools of a measurement laboratory.
- are used to check and calibrate general laboratory instruments for accuracy and performance or
- to perform comparison measurements in industrial applications.
- A manufacturer of precision resistances, for example, may use a standard resistor (a working standard) in the quality control department of his plant to check his testing equipment.
- he verifies that his measurement setup performs within the required limits of accuracy.

# Standards For Mass, Length, And Volume

# Standards For Mass, Length, And Volume

- The metric unit of mass was originally defined as the mass of a cubic decimeter of water at its temperature of maximum density.
- The material representation of this unit is the International Prototype Kilogram, preserved at the International Bureau of Weights and Measures near Paris.
- The primary standard of mass in North America is the United States Prototype Kilogram, preserved by the NUS to an accuracy of 1 part in $10^8$ and
- occasionally verified against the standard at the International Bureau.

# Standards For Mass, Length, And Volume

- Secondary standards of mass, kept by the industrial laboratories, have an accuracy of 1 ppm (part per million) and
  - may be verified against the NBS primary standard.
- Commercial working standards are available in a wide range of values to suit almost any application.
  - Their accuracy is in the order of 5 ppm.
  - are checked against the secondary laboratory standards.
- The pound (lb), established by the Weights and Measures Act of 1963 (which actually came into effect on January 31, 1964),
  - is defined as equal to 0.45359237 kg exactly.
  - All countries which retain the pound as the basic unit of measurement have now adopted the new definition, which supersedes the former imperial standard pound made of platinum.

# System of Units of Measurement

- Fundamental Units
  - Those units which are used for naturally existing distinct quantities and cannot be expressed/measured in term of anything else. e.g. Length, Mass, Time
- Derived Units
  - Those units expressed in terms of fundamental units for different physically existing quantities are Derived Units. e.g. speed, velocity, force, etc

# System of Units of Measurement

- Fundamental Units
  - Measures of certain physical quantities in the thermal, electrical, and illumination disciplines are also represented by fundamental units.
  - Consider Meter, foot, yard for Length
  - Gram, Kilogram, milligram for Mass
  - Sec, hour, minute for Time

# System of Units of Measurement

- FPS – Foot Pound Second – The British
- MKS – Meter, Kilogram and Second
- CGS – Centimeter Gram Second-designed for practical engg. applications
- French system - Universal system of standard

- MTS-Meter Ton Second in France designed for engg. purpose
- SI –Meter Kilogram Second Ampere

# Electric and Magnetic Units

- The practical electrical and magnetic units, such as the volt, ampere, ohm, henry, etc., were first derived in the CGS systems of units.
- Coulomb's law states that

$$F = k\frac{Q_1 Q_2}{r^2} \qquad \text{or} \qquad F = k\frac{Q_1 Q_2}{\varepsilon r^2}$$

$$\text{dyne} = \frac{\text{gcm}}{\text{s}^2} = \frac{Q^2}{(\varepsilon_0 = 1)\text{cm}^2}$$

Dimensionally $\quad Q = cm^{3/2} g^{1/2} s^{-1}$

# Electric and Magnetic Units

- The CGSe unit of electric charge was given the name *statcoulomb*.
- The derived unit of electric charge in the CGSe system of units allowed other electrical units to be determined by their defining equations. For example, electric current (symbol ***I***) is defined as the rate of flow of electric charge and is expressed as

$$I = \frac{Q}{t}$$

- Termed as Statampere

# Electric and Magnetic Units

- Coulombs law for two magnets can be expressed as

$$F = k\frac{m_1 m_2}{r^2}$$

- Dimensionally $m = cm^{3/2} g^{1/2} s^{-1}$
- Note that it is similar to the dimension of Q but a different quantity.
- Different derived units are expressed in terms of above formula in CGSm system of units.

# System International of Units(MKS)

| **Quantity** | **Unit** | **Symbol** |
|---|---|---|
| Length | Meter | m |
| Mass | Kilogram | kg |
| Time | Second | s |
| Electric current | Ampere | A |
| Thermodynamic temperature | Kelvin | K |
| Luminous intensity | Candela | cd |

# Conversion of SI Units to Other System of units

- MKS to FPS

**TABLE 2-5** English into SI Conversion

| Quantity | English unit | Symbol | Metric equivalent | Reciprocal |
|---|---|---|---|---|
| Length | 1 foot | ft | 30.48 cm | 0.0328084 |
| | 1 inch | in. | 25.4 mm | 0.0393701 |
| Area | 1 square foot | $ft^2$ | $9.29030 \times 10^2\ cm^2$ | $0.0107639 \times 10^{-2}$ |
| | 1 square inch | $in.^2$ | $6.4516 \times 10^2\ mm^2$ | $0.155000 \times 10^{-2}$ |
| Volume | 1 cubic foot | $ft^3$ | $0.0283168\ m^3$ | 35.3147 |
| Mass | 1 pound (avdp) | lb | 0.45359237 kg | 2.20462 |
| Density | 1 pound per cubic foot | $lb/ft^3$ | $16.0185\ kg/m^3$ | 0.062428 |
| Velocity | 1 foot per second | ft/s | 0.3048 m/s | 3.28084 |
| Force | 1 poundal | pdl | 0.138255 N | 7.23301 |
| Work, energy | 1 foot-poundal | ft pdl | 0.0421401 J | 23.7304 |
| Power | 1 horsepower | hp | 745.7 W | 0.00134102 |
| Temperature | degree F | °F | $5(t - 32)/9$°C | — |

# Conversion of SI Units to Other System of units

- MKS to FPS

**EXAMPLE 2-1**

The floor area of an office building is 5,000 $m^2$. Calculate the floor area in $ft^2$.

**SOLUTION** To convert the unit $m^2$ into the new unit $ft^2$, we must know the relation between them. In Table 2-5 the metric equivalent of 1 ft is 30.48 cm, or 1 ft = 0.3048 m. Therefore

$$A = 5{,}000\ \text{m}^2 \times \left(\frac{1\ \text{ft}}{0.3048\ \text{m}}\right)^2 = 53{,}820\ \text{ft}^2$$

# Conversion of SI Units to Other System of units

- MKS to FPS

**EXAMPLE 2-5**

The speed limit on a highway is 60 km/hr. Calculate the limit in (a) mi/hr; (b) ft/s.

**SOLUTION**

$$\text{(a) Speed limit} = \frac{60\text{ km}}{\text{hr}} \times \frac{10^3\text{ m}}{1\text{ km}} \times \frac{10^2\text{ cm}}{1\text{ m}} \times \frac{1\text{ in.}}{2.54\text{ cm}} \times \frac{1\text{ ft}}{12\text{ in.}}$$

$$\times \frac{1\text{ mi}}{5{,}280\text{ ft}} = 37.3\text{ mi/hr}$$

$$\text{(b) Speed limit} = \frac{37.3\text{ mi}}{\text{hr}} \times \frac{5{,}280\text{ ft}}{1\text{ mi}} \times \frac{1\text{ hr}}{3.6 \times 10^3\text{ s}} = 54.9\text{ ft/s}$$

# Standards of Measurements

- Mass
  - The metric unit of mass was originally defined as the mass of a cubic decimeter of water at its temperature of maximum density.
  - The primary standard of mass in North America is the United States Prototype Kilogram, preserved by the NUS to an accuracy of 1 part in $10^8$ and occasionally verified against the standard at the International Bureau.

# Standards of Measurements

- Length(Meter)
  - One meter is the distance light that propagates in a vacuum in 1/299,792,458 seconds.
- Volume
  - The unit of volume is a derived quantity and is not represented by an international standard.
  - Primary standards of volume, calibrated in terms of the absolute dimensions of length and mass.

# Standards of Measurements

- Time(Second)
- The International Committee of Weights and Measures has defined the second in terms of the frequency of the cesium transition (Cs), assigning a value of 9,192,631,770 Hz to the hyperfine transition of the cesium atom unperturbed by external fields.

# Electrical Standards of Measurements

- Absolute Ampere
  - The International Ampere was defined as that current which deposits silver at the rate of 1.118 mg/s from a standard silver nitrate solution.
  - Absolute Ampere is made by means of a current balance, which weighs the force exerted between two current-carrying coils.

# Electrical Standards of Measurements

- Resistance Standards
  - The standard resistor is a coil of wire of some alloy like manganin which has a high electrical resistivity and a low temperature coefficient of resistance ***(almost constant temperature-resistance relationship).***
  - The resistance coil is mounted in a double-walled sealed container (Fig. 3-I) to prevent changes in resistance due to moisture conditions in the atmosphere.

# Electrical Standards of Measurements

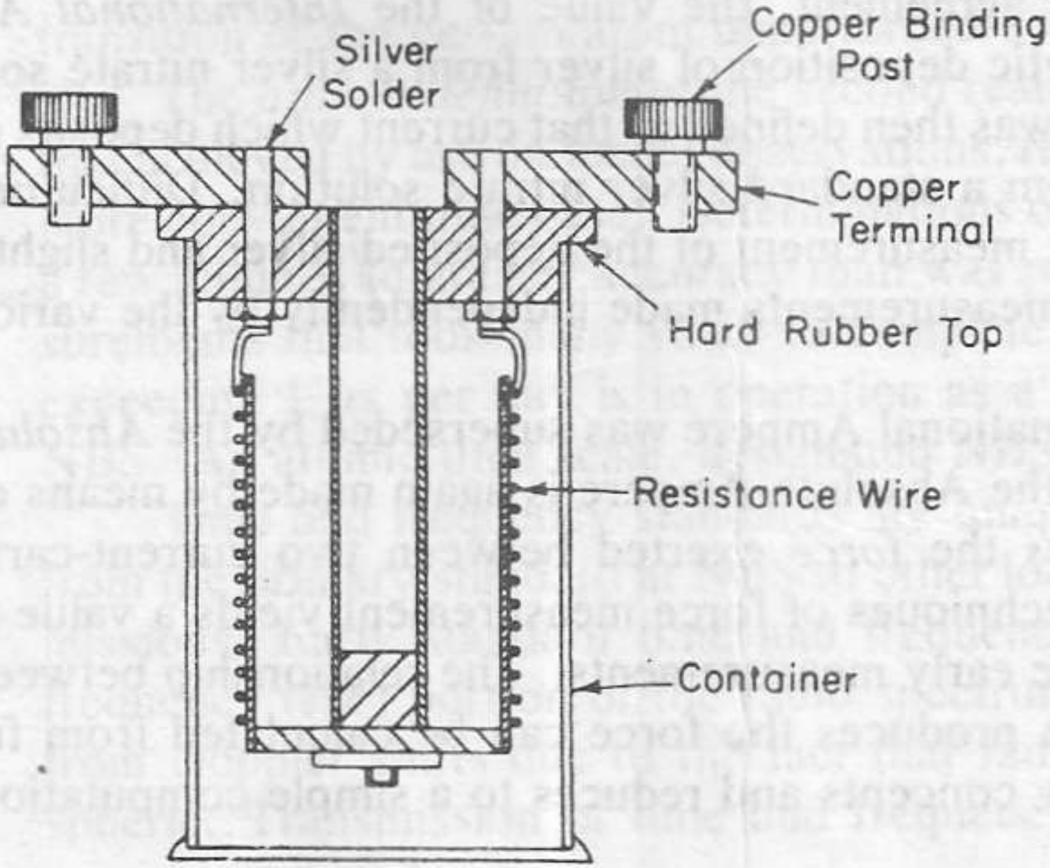


**Figure 3-1** Cross-sectional view of a double-walled resistance standard. (Courtesy of Hewlett-Packard Co.)

# Electrical Standards of Measurements

- Voltage
  - A thin-film junction is cooled to nearly absolute zero and irradiated with microwave energy. A voltage is developed across the junction, which is related to the irradiating frequency by the following relationship:

$$v = \frac{hf}{2e}$$

- Where h = Planck's constant (6.63 X $10^{-34}$ J-s)
- e = charge of an electron (1.602 x $10^{-19}$ C)
- f = frequency of the microwave irradiation

# Electrical Standards of Measurements

- The only irradiating frequency is a variable in the equation, the standard volt is related to the standard of time/frequency.
- The major method of transferring the volt from the standard based on the Josephson junction to secondary standards used for calibration is the standard cell.
- This device is called the normal or saturated Weston cell.

# Electrical Standards of Measurements

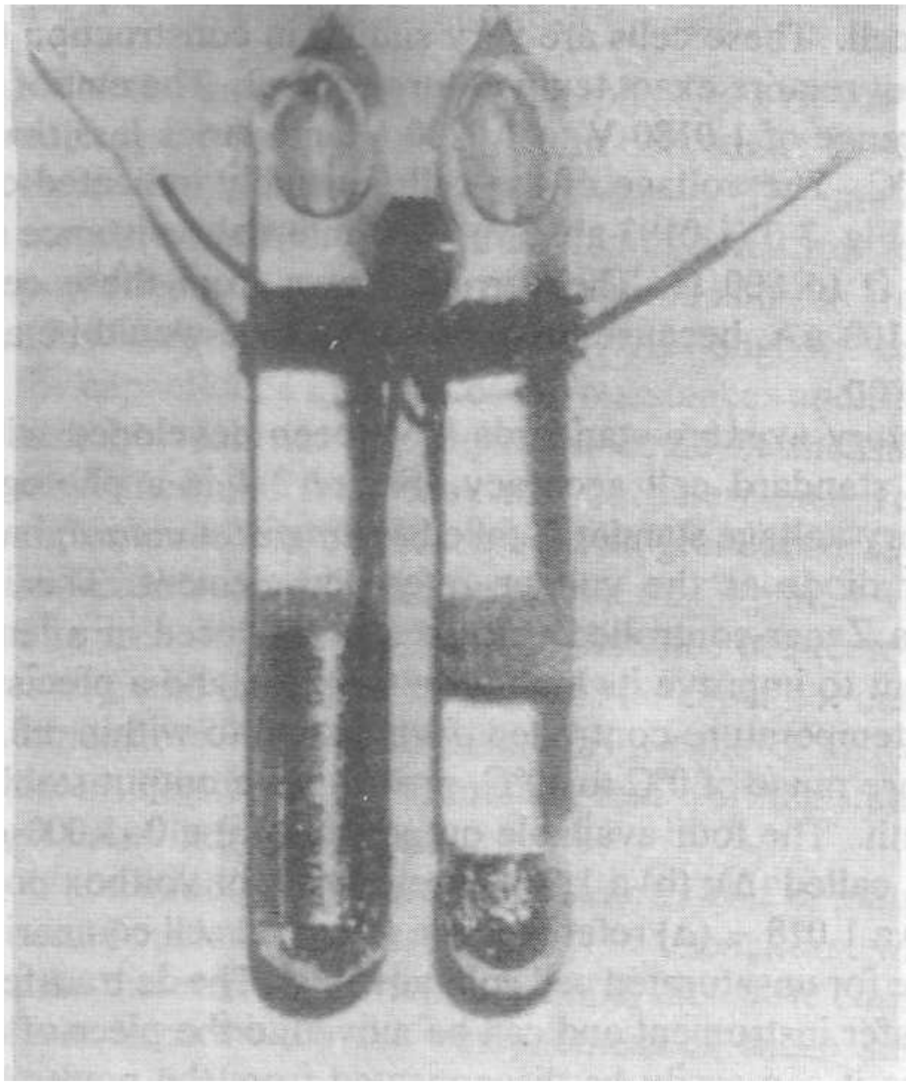

**Figure 3-3** Weston cadmium cell: emf of 1.0193, accuracy of 0.1%. (Courtesy of The Eppley Laboratory, Inc.)

# Electrical Standards of Measurements

- Capacitance Standards
  - The unit of capacitance (the farad) can be measured with a Maxwell dc commutated bridge, where the capacitance is computed from the resistive bridge arms and the frequency of the dc commutation.
  - Since both resistance and frequency can be determined very accurately, the value of the capacitance can be measured with great accuracy.

# Electrical Standards of Measurements

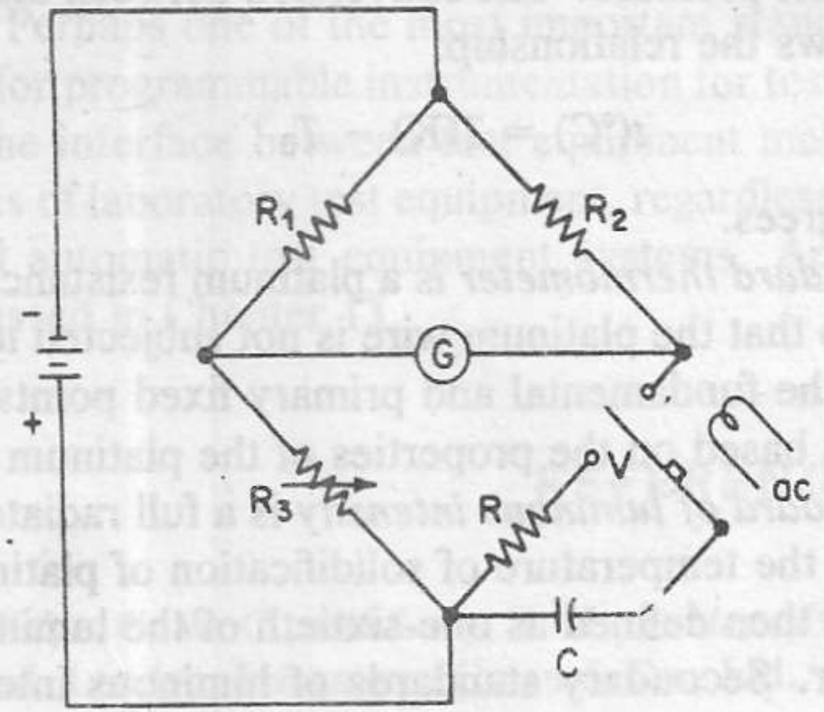


**Figure 3-5** Commutated dc method for measuring capacitance. Capacitor $C$ is alternately charged and discharged through the commutating contact and resistor $R$. Bridge balance is obtained by adjustment of $R_3$, allowing exact determination of the capacitance value in terms of bridge-arm constants and frequency commutation.

# Electrical Standards of Measurements

- Inductance Standards
  - The primary inductance standard is derived from the ohm and the farad, rather than from the large geometrically constructed inductors used in the determination of the absolute value of the ohm.
  - The NBS selected a Campbell standard of mutual inductance as the primary standard for both mutual and self-inductance.

# IEEE STANDARDS

- A slightly different type of standard is published and maintained by the Institute of Electrical and Electronics Engineers, IEEE, an engineering society headquartered in New York City.
- These standards are not physical items that are available for comparison and checking of secondary standards but are standard procedures, nomenclature, definitions, etc.

# IEEE STANDARDS

- A large group of the IEEE standards is the standard test methods for testing and evaluating various electronics systems and components.
- Another useful standard is the specifying of test equipment.
- Safety of wiring for power plants, ships, industrial buildings, etc.
- Standard schematic and logic symbols for Engineering drawing standardization.

# Thank you

- Questions

# Quiz

1. **Convert the practical unit of Electrical energy into SI unit of energy.**
2. **Calculate the voltage of a battery if a charge of $5x10^{-6}$ coulomb residing on the positive battery terminal possesses $6x10^{-2}$ joules of energy**