# INSTRUMENTATION I
# EMEg3151

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# COURSE OUTLINE

- CHAPTER 1 General principles of Instruments
  - Introduction
  - Basic Concepts of Measurement
  - Functional elements of an instrument system
  - Performance Characteristics – Static and Dynamic
  - Noise, Error and analysis

# COURSE OUTLINE

- CHAPTER 2 Units and Dimensions
  - Fundamental and derived units
  - Dimensions of Quantities
  - SI units
  - Definition of units
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# COURSE OUTLINE

- CHAPTER 3 Measurements of resistance, inductance & capacitance
  - Kelvin bridge
  - Wheatstone bridge
  - Megger earth tester
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  - Hay bridge
  - Anderson bridge, Owen bridge, Schering bridge, Campbell bridge, Wien bridge

# COURSE OUTLINE

- CHAPTER 4 Analog instruments
  - Permanent moving coil instrument
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  - Dynamometer watt meter
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  - Digital voltmeter

# COURSE OUTLINE

- CHAPTER 5 Measurement of energy and industrial metering
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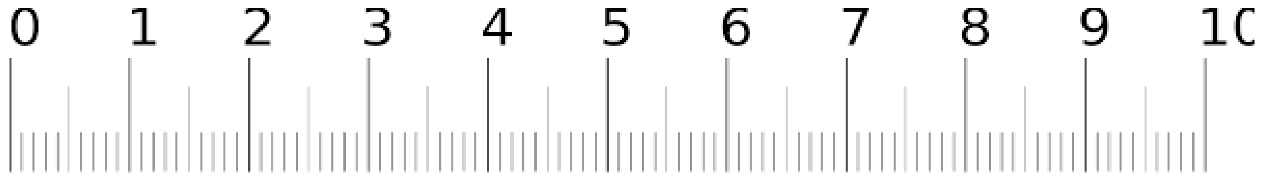
  - Two element energy meter
  - Industrial meter and tariff maximum demand indicator

# CHAPTER 1
# General principles of Instruments

- **Measurement:**
  - The measurement of a given quantity is essentially an act or the result of comparison between the quantity(whose magnitude is unknown)and a predefined standards
  - Since two quantities are compared the result is expressed in numerical values

Examples- ruler and balance



# Measurement

- In order that the results of the measurement are meaningful, there are two basic requirements
  - The standard used for comparison purpose must be accurately defined and should be commonly accepted
  - The apparatus used and the method adopted must be provable

# Method of Measurement

- Direct Method
  - The unknown quantity (measurand) is directly compared against a standard. The result is expressed as a numerical number and a unit
  - Direct method are quite common for the measurement of physical quantities like Length, Mass and time

  Example human measuring the length

# Method of Measurement

- Indirect Method
  - In Engineering application Measurement systems are used. These measurement systems are uses indirect methods for measurement purpose
  - Example
    - Industrial measurement

# INSTRUMENT

- Measurement generally involves using an instrument as a physical means of determining a quantity or variable
- The instrument serves as an extension of human faculties and enables the man to determine the value of unknown quantity which his unaided human faculties cannot measure
- An instrument may be define as a device for determining the value or magnitude of a quantity or variable.

# Classification of instruments

- The instruments can also be divided into separate classes according to several criteria as,
  - Analog or digital instruments
  - deflection or null type instruments
  - power operated (active) or self generating (passive) instruments
  - contacting or non-contacting instruments
  - mechanical or electrical instruments
  - monitoring or control instruments

# Analog instruments

- Signals which vary continuously with the change in the measurand are *analog signals and the devices producing them are analog instruments. The deflection type dynamometer type wattmeter is a good example of an analog instrument*
- As the input value changes, the moving system or pointer exhibits a smooth continuous motion


# Digital instruments

- The signals which vary in discrete steps and have only finite number of values in any given range are *digital signals and the associated devices are digital instruments.*
- A digital instrument has an output varying in discrete steps
- An electronic counter is an example of a digital instrument.


# Deflection Instruments

- If the quantity is to be directly measured, then *deflection methods are used. For e.g., ammeter, voltmeter, etc. acting as meters indicating the value of the measurand by the deflection of a pointer over a graduated and calibrated scale. Alternatively*

# Null type instruments

- if the value is measured based on the null balance conditions, then it is a *null method.*
- *Null methods are used only to detect the null condition of a measurand through a given path or circuit.*
- *AC/DC Bridge measurements for measurement of resistance, inductance, capacitance, frequency, etc. are null methods.*
- *They involve balance detection by using null detectors, such as, Galvanometer, Vibration Galvanometers and Head Phones.*
- *Null instruments are more accurate than the deflection instruments.*

# Power operated (active) instruments

- If the output of the instrument is entirely produced by the measurand, then it is an *active instrument.*
- *These are the power operated instruments requiring some source of auxiliary power for their operation such as compressed air, electricity and hydraulic supply.*

# Self generating (passive) instruments

- if the measurand modulates the magnitude of some external power source, then it is a *passive instrument. Passive instruments are self generating instruments where the energy requirements are met entirely from the input signal.*

# *Contacting type instruments*

- *Contacting type instruments are those which are kept in the measuring medium itself. For*
- *e.g., clinical thermometer.*

# A *non-contacting or proximity type instrument*

- A *non-contacting or proximity type instrument measures the desired input even though it is not in close contact with the measuring medium.*
- *e.g., optical pyrometer measuring the temperature of a blast furnace, variable reluctance tachometer measuring the speed of a rotating part, etc.*

# *Mechanical instruments*

- *Mechanical instruments are very reliable for static conditions. Their parts are very bulky, rigid and have a heavy mass. Hence they cannot respond rapidly to measurements of dynamic and transient conditions. Besides, many of them are the potential sources of noise.*

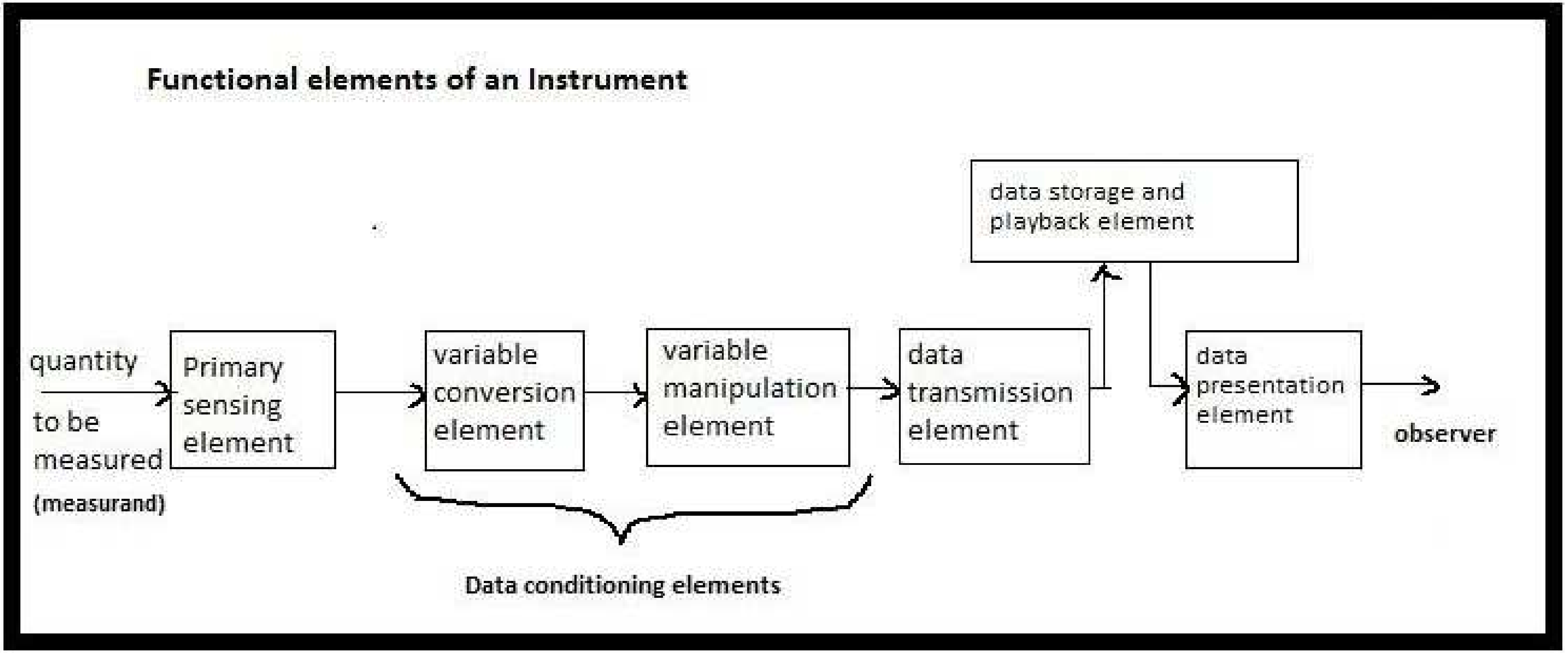
# *Electrical instruments*

- *electrical instruments are very rapid in response. However, their operating mechanism normally depends on a mechanical meter movement as an indicating device.*

# *Monitoring and control instruments*

- *Monitoring instruments are useful for monitoring functions.*
- *Example display devices*
- *If their output is in a form that can be directly included as part of an automatic control system, then they become control instruments.*

# ELEMENTS OF A GENERALIZED MEASUREMENT SYSTEM:



# Primary sensing element:

- The quantity under measurement makes its first contact with the primary sensing element of a measurement system.
- i.e., the measurand- (the unknown quantity which is to be measured) is first detected by primary sensor which gives the output in a different analogous form
- This output is then converted into an electrical signal by a transducer - (which converts energy from one form to another).
- The first stage of a measurement system is known as a detector

# Transducer stage Variable conversion element:

- The output of the primary sensing element may be electrical signal of any form; it may be voltage, a frequency or some other electrical Parameter
- For the instrument to perform the desired function, it may be necessary to convert this output to some other suitable form.

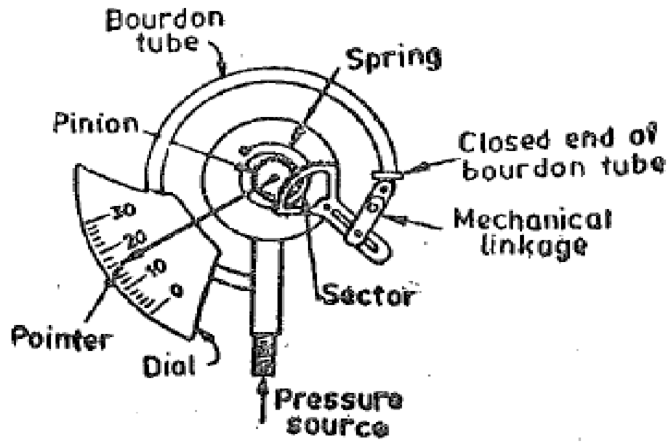
# Variable manipulation element:

- The function of this element is to manipulate the signal presented to it preserving the original nature of the signal
- It is not necessary that a variable manipulation element should follow the variable conversion element
- Some non-linear processes like modulation, detection, sampling, filtering, chopping etc.,are performed on the signal to bring it to the desired form to be accepted by the next stage of measurement system
- This process of conversion is called signal conditioning’
- The term signal conditioning includes many other functions in addition to Variable conversion & Variable manipulation

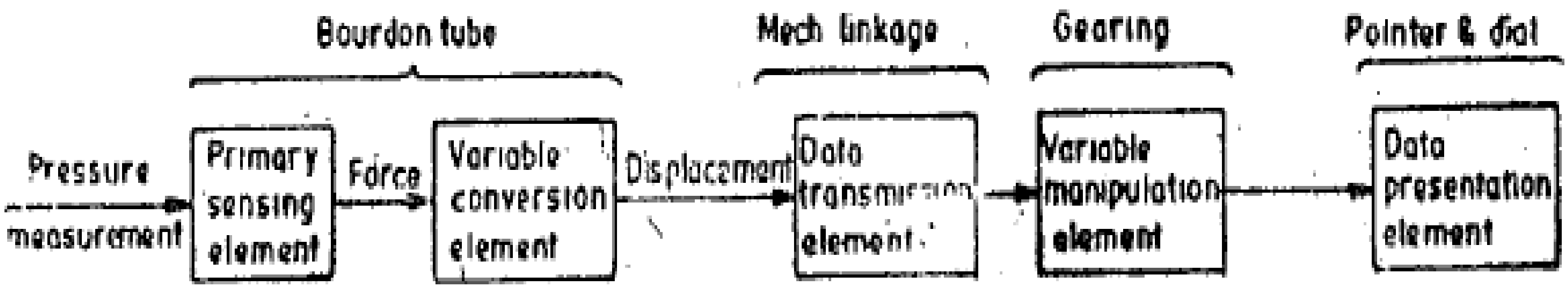
# Data presentation element

- In case data is to be monitored, visual display devices are needed
- These devices may be analog or digital indicating instruments like ammeters, voltmeters etc
- In case data is to be recorded, recorders like magnetic tapes, high speed camera & TV equipment, CRT, printers may be used
- For control & analysis purpose microprocessor or computers may be used. The final stage in a measurement system is known as terminating stage’

# Example for functional elements of instrument bourdon tube




**Bourdon tube pressure gauge.**




**Schematic diagram of a bourdon tube pressure gauge.**

# Performance Characteristics of an instrument

The following terms are used to understand the performance of an instrument

1. Range and span: The range defines the limits between which the input can vary, the span is the maximum value minus the minimum value.

   Ex: A transducer may have a range of 0 to 100 volts and a span of 100 v

2. Error: it is the difference between the result of measurement and the true value of the quantity being measured

Hence error = measured value - true value

Ex: If the temperature required or actual is $50^0$c and the measured is $54^0$c then error is $+4^0$c and if the measured is $46^0$c then the error is $-4^0$c

3. Accuracy: It is the extent to which the value indicated by a measurement system might be wrong. This is often expressed as % of full range output

Ex: A voltmeter may have an accuracy of +/-5% and if the full range is 0 to 1000v then the accuracy is +/-5% of 1000v or +/-50 to the true reading.

4. Sensitivity: It is the relationship indicating how much output we get per unit input. It is the ratio of o/p to i/p.

Ex: A voltmeter may have a sensitivity of +/-1% of the reading per $^0$c change in temperature or any other external disturbances.

5. Hysteresis error: It is the difference between the indications of a measuring instrument when the same value of the measured quantity is reached by increasing or decreasing that quantity

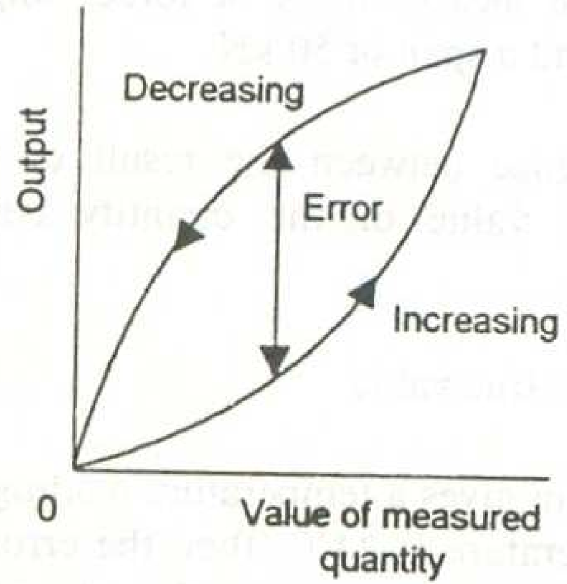



Fig. 2.1 Hysteresis

6. Non-linearity error: In many calculations it is assumed that the transducers have a linear relationship between input and the output. This assumption itself will result in the error as the relationship will not be linear. This error or the maximum difference from the straight line is defined as Non-linearity error

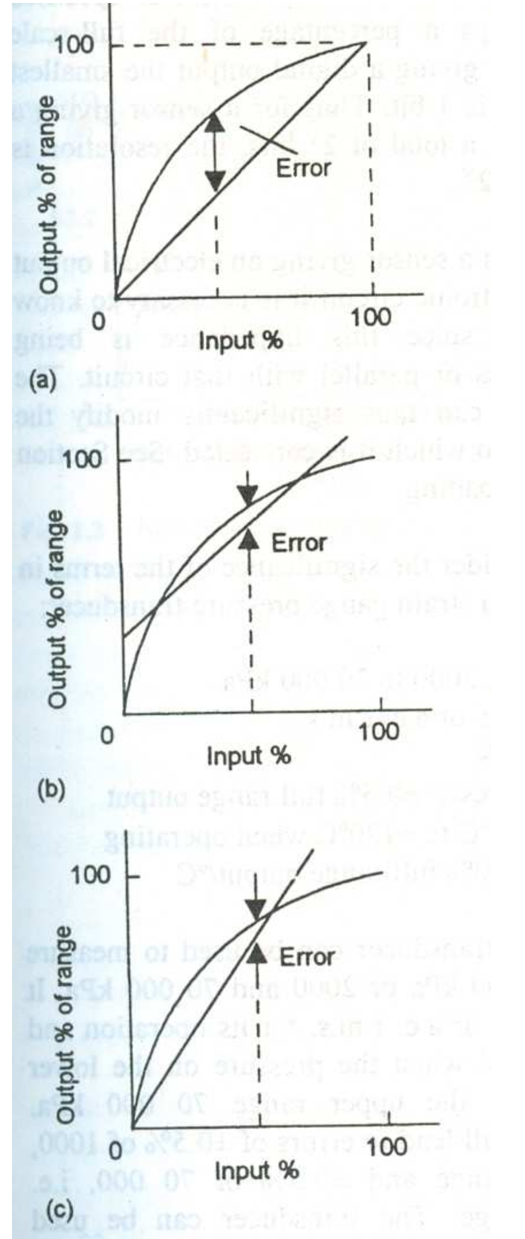



**Fig. 2.2** Non-linearity error using:
(a) end-range values,
(b) best straight line for all values,
(c) best straight line through zero point

7. Repeatability or reproducibility: It is its ability to give the same output for repeated applications of same input

8. Stability: It is the ability of the transducer to give the same output when used to measure a constant input over a period of time

9. Dead band/time: It is the length of the time from the application of an input until the output begins to respond and change

10. Resolution: The resolution is the smallest change value of the input that the instrument produces an observable change in the output

# Example

A pressure gauge is observed to have the following specifications

Range: 100 to 1000 kpa

Supply voltage: 10V, DC or AC r.m.s

Full range output: 40mV

Non-linearity and hysteresis: +/- 0.5% full range output

Temperature range -50$^{o}$C to +100$^{o}$C when operating

Thermal zero shift: 0.03% full range output/$^{o}$C

# ERROR

- it is the difference between the result of measurement and the true value of the quantity being measured

  Hence error = measured value - true value

Ex: If the temperature required or actual is $50^0$c and the measured is $54^0$c then error is $+4^0$c and if the measured is $46^0$c then the error is $-4^0$c

# Types of Errors

- Gross Errors
  - This class of error mainly covers human mistakes in reading instruments and recording and calculating measurement result
- Systematic Errors
- Random Errors

# Gross Errors

- This class of error mainly covers human mistakes in reading instruments and recording and calculating measurement result
- The responsibility of the mistake normally lies with the experimenter.
- The Experimenter may grossly misread the scale. Example due to an oversight, Read the temperature as 31.5degree C while the actual reading may be 21.5 degree C

# Avoiding method for Gross Error

- Gross Errors may be of any amount and therefore their mathematical analysis is impossible, they can be avoided by adopting two means the are
  - Great care should be taken in reading and recording the data
  - Three or even more reading should be taken for the quality under measurement

# Systematic Error

- These types of errors are divided into three categories
  - Instrumental Errors
  - Environmental Errors
  - Observational Errors

# Instrumental Errors

- These errors arise due to three main reasons
  - Due to inherent short coming in the instrument
  - Due to misuse of the instrument
  - Due to loading effect of instrument

# Inherent Shortcoming of Instrument

- Its due to its mechanical structure . They may be due to construction, calibration or operation of the instrument or measuring device
- Example if the spring (used to producing control torque) of a permanent magnet instrument has become weak, the instrument will always read high

# Avoiding of inherent short coming in instrument

- The procedure of measurement must be carefully planned. Substitution method or calibration against standards may be used for the purpose
- Correction factors should be applied after determining the instrumental errors
- The instrument may be re-calibrated carefully

# Misuse of Instrument

- Improper initialization in the initial setup of the instrument
- Example instrument may be failure to adjust the zero of instrument, poor initial adjustment

# Loading Effect

- One of the most common errors committed by beginners, is the improper use of an instrument for measurement work
- Example well calibrated voltmeter used for above then rated voltage

# Environmental Errors

- These errors are due to conditions external to the measuring device including conditions in the area surrounding the instrument
- These may be effect of temperature, pressure, humidity, dust, Vibration or external magnetic or electrostatic field

# Elimination of environmental Errors

- Arrangement are made to keep the condition as nearly as constant as possible , temperature can be kept constant by keeping the equipment in a temperature controlled enclosure.
- Using equipment which is immune to these effects example variation in resistance with temperature can be minimized by using resistance materials.

# Elimination of environmental Errors

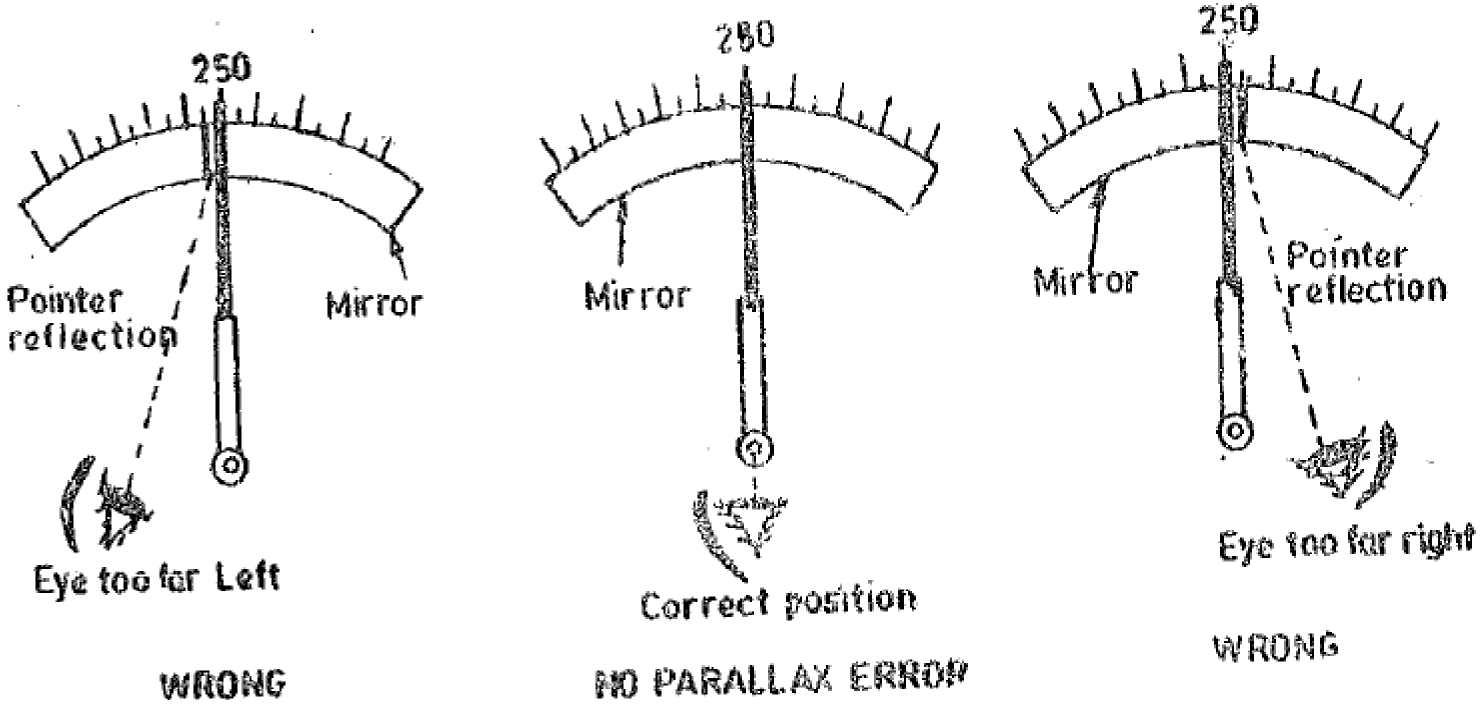
- Employing technique which eliminate the efforts of these disturbances. Example the effect of humidity dust etc. can be entirely eliminated by sealing the equipment
- Applying the computed corrections
  – calculation of the error to adjust the correction

# Observational Errors

- There are many source of observational Errors Example the pointer of a voltmeter rests slightly above the surface of the scale
- Thus error on account of PARALLAX will be incurred unless the line of vision of the observer is exactly above the pointer

# Observational Errors

- To minimize parallax errors, highly accurate meters are provided with mirrors scale as shown below



# Random(Residual) Errors

- It has been consistently found that experimental result shows variation from one reading to another, even after all systematic errors have been accounted for
- These errors are due to a multitude of small factors which change or fluctuate from one measurement to another
- The happening or disturbances about which we are unaware are lumped factors called “Random “ or “Residual”