Semester-VI

B.Sc (Honours) in Physics

DSE 4: **Experimental Techniques**

Lecture

on

Error and uncertainty analysis & Different types of Error

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Lecture- II

Syllabus

- **Measurements**
  - Accuracy and precision and Significant figures.
  - Error and uncertainty analysis.
  - Types of errors:
    - Gross error,
    - Systematic error,
    - Random error.
  - Statistical analysis of data
    - Arithmetic mean,
    - Deviation from mean,
    - Average deviation,
    - Standard deviation,
    - Chi-square and
  - Curve fitting.
  - Guassian distribution.

Error and uncertainty analysis

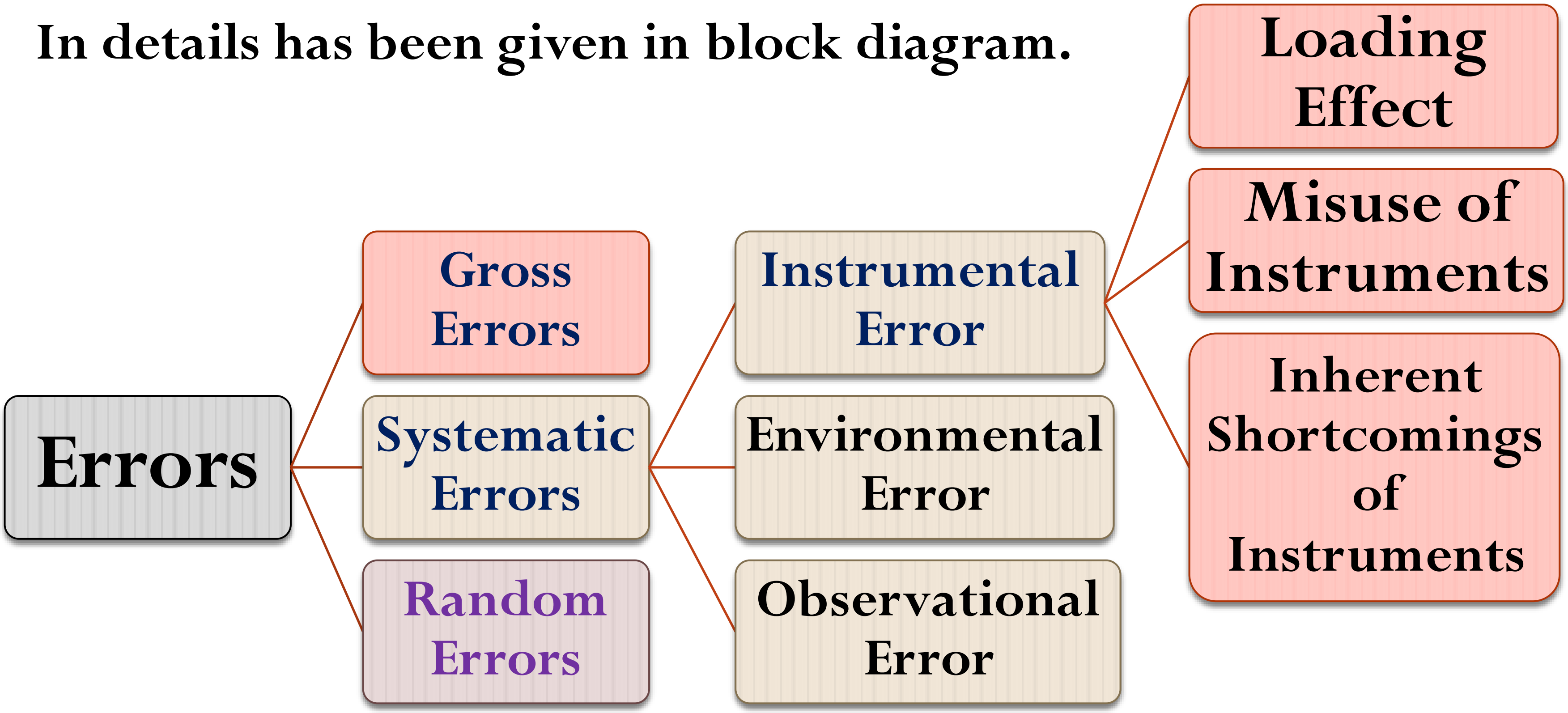
The process of evaluating this uncertainty associated with a measurement result is often called uncertainty **analysis** or **error analysis**. The complete statement of a measured value should include an estimate of the level of confidence associated with the value.

Types of Errors in Measurement

The error may arise from the different source and are usually classified into the following types. These types are

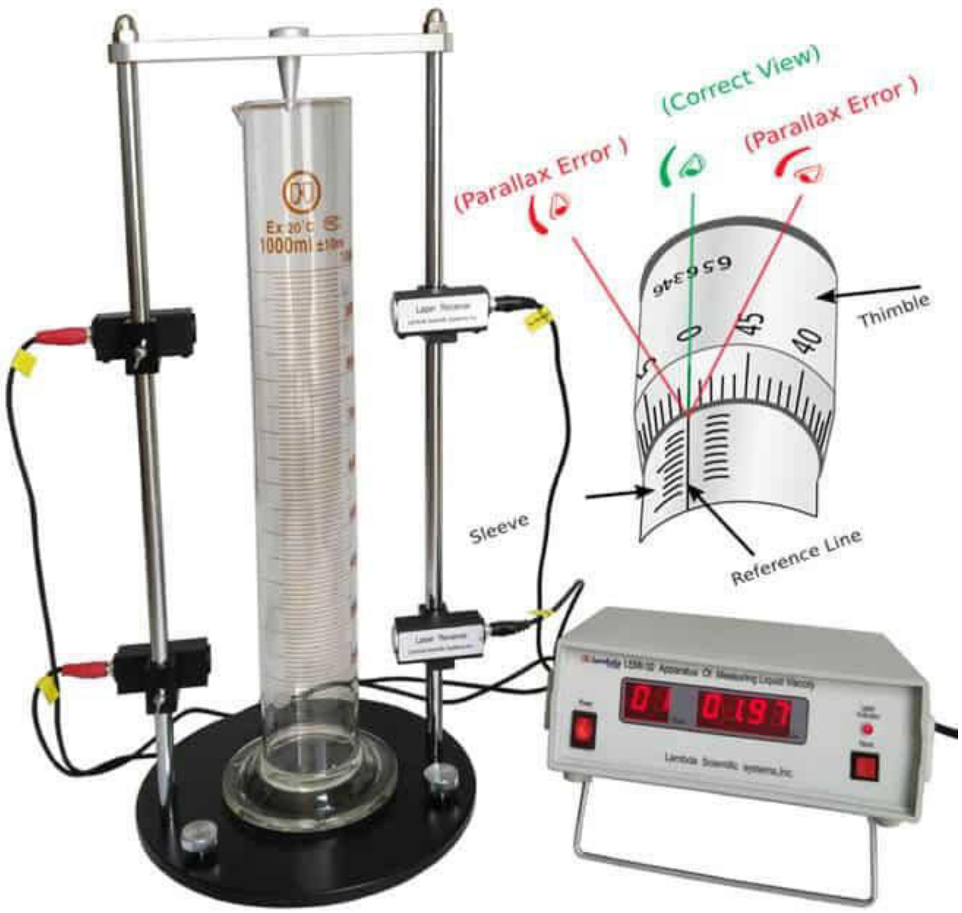
- Gross Errors
- Systematic Errors
- Random Errors

In details has been given in block diagram.



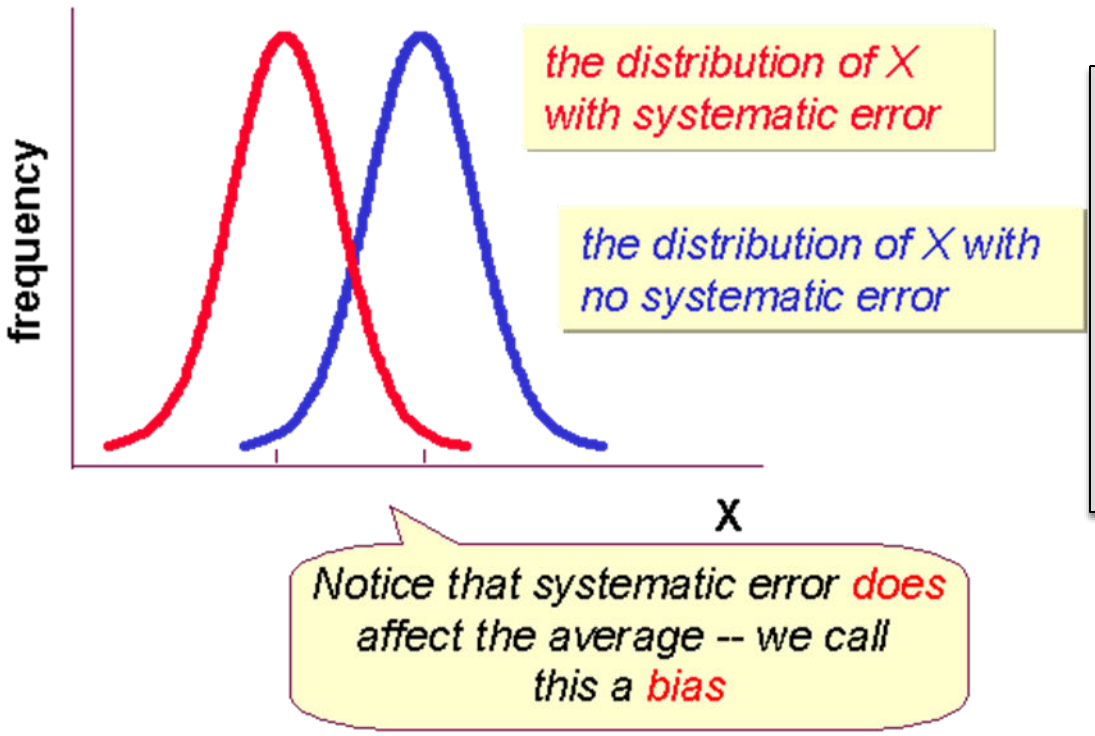
Gross Errors

Gross errors are caused by mistake in using instruments or meter, calculating measurement and recording data results. The best example of these errors is a person or operator reading pressure gage 1.01N/m2 as 1.10N/m2. It may be due to the person's bad habit of not properly remembering data at the time of taking down reading, writing and calculating, and then presenting the wrong data at a later time. This may be the reason for gross errors in the reported data, and such errors may end up in calculation of the final results, thus deviating results.



Systematic Errors

Systematic error is caused by any factors that **systematically affect** measurement of the variable across the sample. For instance, if there is loud traffic going by just outside of a classroom where students are taking a test, this noise is liable to affect all of the children's scores – in this case, systematically lowering them. Unlike random error, systematic errors tend to be consistently either positive or negative – because of this, systematic error is sometimes considered to be ***bias*** in measurement.



Types of Systematic Errors

- Systematic Errors
  - Instrumental Error
  - Environmental Error
  - Observational Error

Instrumental Error

These errors mainly arise due to the three main reasons:

a) **Inherent Shortcomings of Instruments**

b) **Misuse of Instrument**

c) **Loading Effect**

(a) Inherent Shortcomings of Instruments: These errors are inherent in instruments because of their mechanical structure. They may be due to construction, calibration or operation of the instruments or electrical measuring devices. These errors may cause the instrument to read too low or too high.

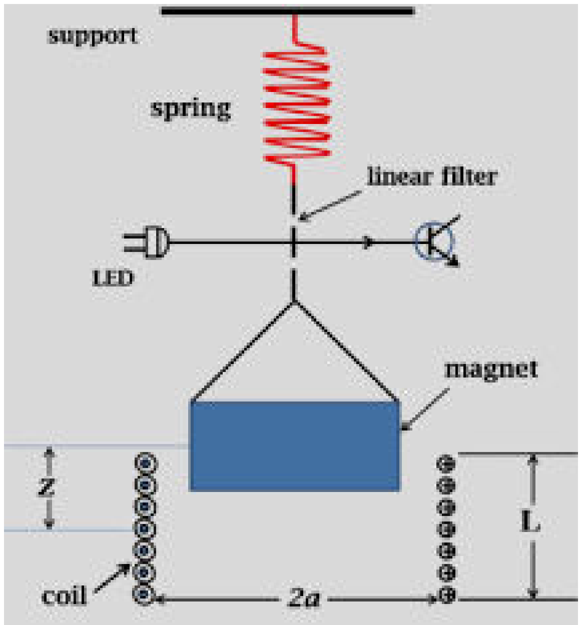
For example, if the spring (used for producing controlling torque) of a permanent magnet instrument has become weak, the instrument will always read high. Errors may be caused because of friction, hysteresis or even gear backlash.

While making precision measurements, we must recognize the possibility of such errors as it is often possible to eliminate them, or at least reduce them to a great extent by using the following methods :

(i) The procedure of measurement must be carefully planned. Substitution methods or calibration against standards may be used for the purpose.

(ii) Correction factors should be applied after determining the instrumental errors.

(iii) The instrument may be re-calibrated carefully.



✓**Spring constant is very high**

✓**Spring constant is very low**

(b) Misuse of Instrument: There is an old saying that instruments are better than the people who use them. Too often, the **types of errors** caused in measurements are due to the fault of the operator than that of the instrument.

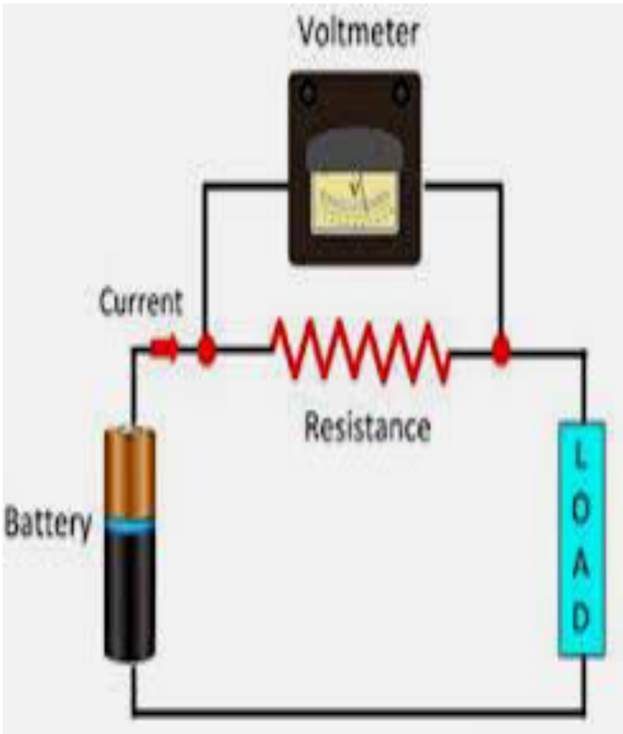
A good **electrical measuring instrument** used in an unintelligent way may give erroneous results. Examples which may be cited for this misuse of the instrument may be a failure to adjust the zero of instruments, poor initial adjustments, using leads of too high a resistance etc.

No doubt the above improper practices may not cause a permanent damage to the instrument but all the same, they cause errors. However, there are certain ill practices like using the instrument contrary to manufacturer's instructions and specifications which in addition to producing errors cause permanent damage to the instruments as a result of overloading and overheating that may ultimately result in failure of the electrical measuring instrument and sometimes the system itself.

(C)Loading effects: One of the most common errors committed by beginners is the improper use of an instrument for measurement work.

For **example**, when the voltmeter is connected to the high resistance circuit it gives a misleading reading, and when it is connected to the low resistance circuit, it gives the dependable reading. This means the voltmeter has a loading effect on the circuit.

The error caused by the loading effect can be overcome by using the meters intelligently. For **example**, when measuring a low resistance by the ammeter-voltmeter method, a voltmeter having a very high value of resistance should be used.



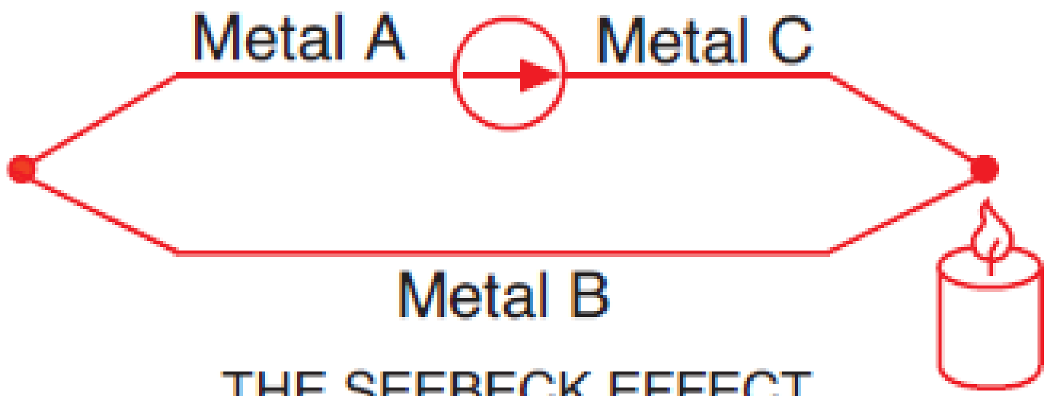
✓ Resistance is very high
✓ Resistance is very low

(ii)Environmental Errors:

These errors in **electrical measuring instruments** are due to conditions external to the measuring device including conditions in the area surrounding the instrument. These may be effects of **temperature**, **pressure**, **humidity**, **dust**, **vibrations** or of **external magnetic** or **electrostatic fields**.

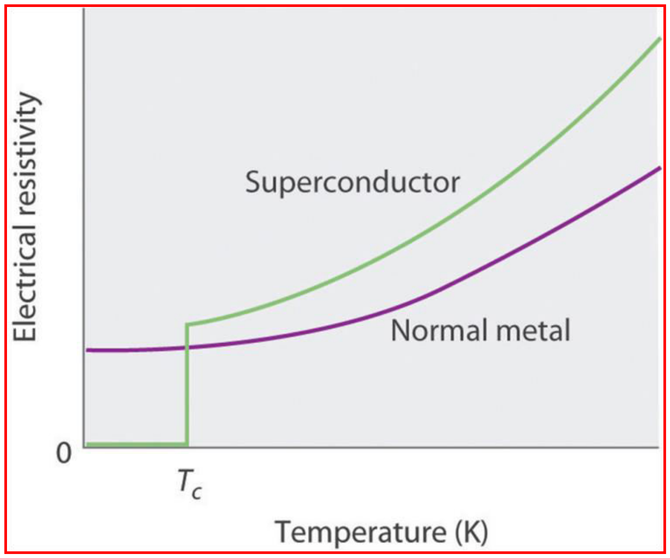
The corrective measures employed to eliminate or to reduce these undesirable effects are:

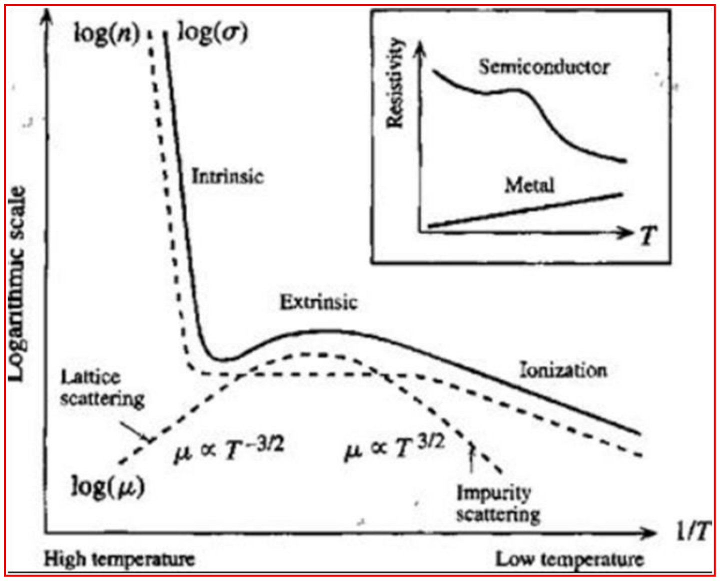
- **Arrangements should be made to keep the conditions as nearly as constant as possible**. For example, the temperature can be kept constant by keeping the equipment in a temperature controlled enclosure.



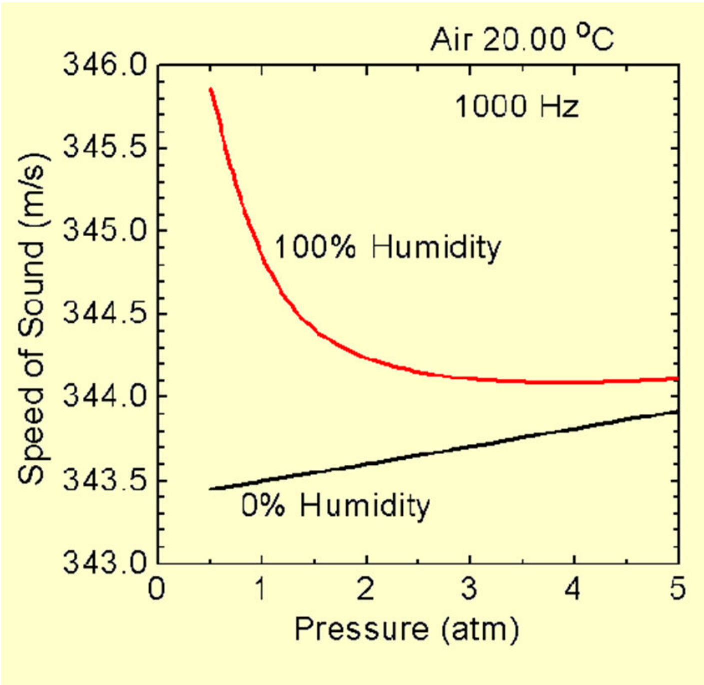
THE SEEBECK EFFECT

➢ **Using equipment which is immune to these effects**. For example, variations in resistance with temperature can be minimized by using resistance materials which have a very low resistance temperature coefficient.





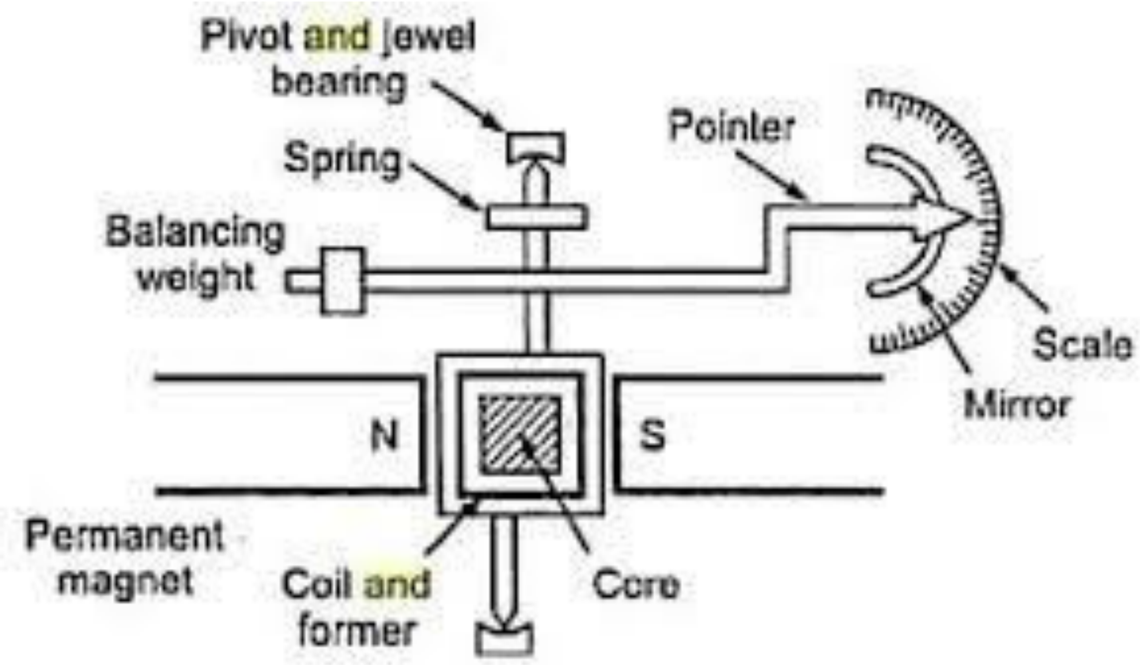
Temperature dependent resistance of conductor, semiconductor and superconductor.

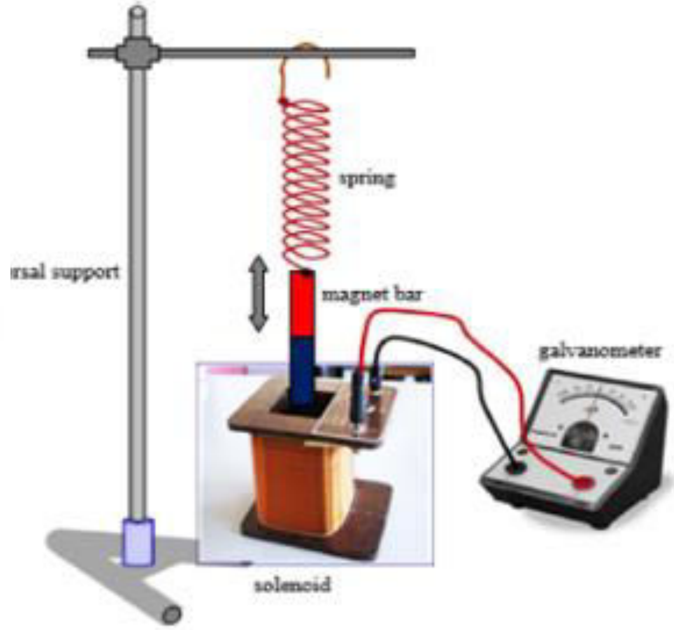


Variation of the speed of sound with pressure at different Humidity

➢ **Employing techniques which eliminate the effects of these disturbances**. For example, the effect of humidity, dust etc. can be entirely eliminated by hermetically sealing the equipment.

➢ In case it is suspected that external magnetic or electrostatic fields can affect the readings of the **electrical measuring instruments**, **magnetic** or **electrostatic shields** may be provided.





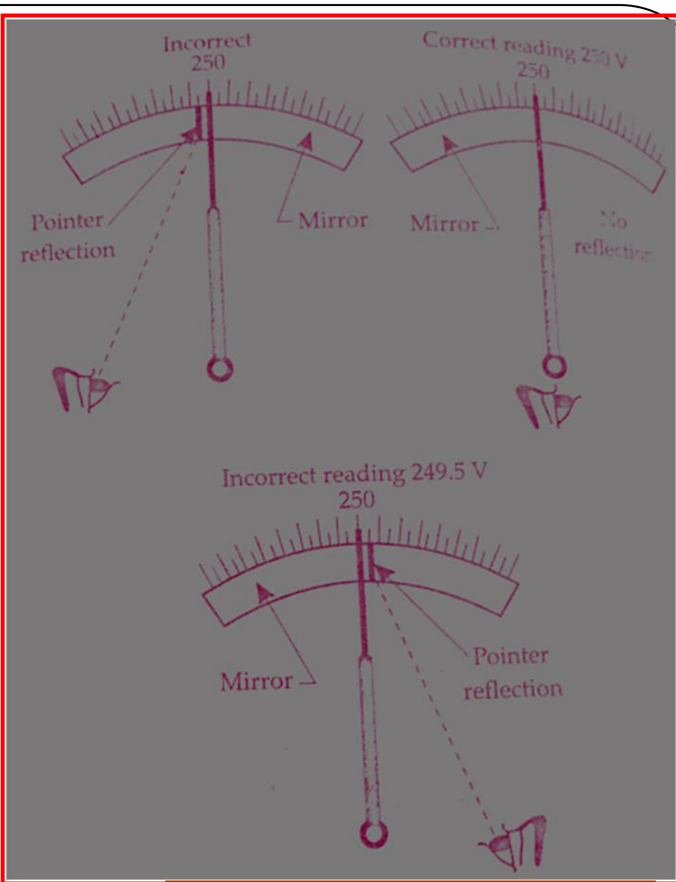
Temperature & Magnetic Field Effect

➢ **Applying computed corrections**: Efforts are normally made to avoid the use of application of computed corrections, but where these corrections are needed and are necessary, they are incorporated for the computations of the results.

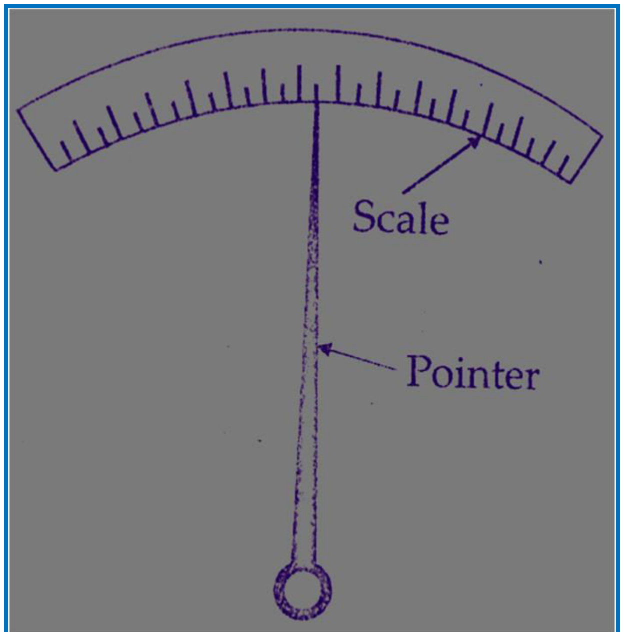
(iii)Observational errors:

There are many sources of observational errors. As an example, the pointer of a voltmeter rests slightly above the surface of the scale. Thus an error on account of PARALLAX will be incurred unless the line of vision of the observer is exactly above the pointer. To minimise parallax errors, highly accurate meters are provided with mirrored scales, as shown in the figure 'errors due to parallax'.

When the pointer's image appears hidden by the pointer, observer's eye is directly in line with the pointer. Although a mirrored scale minimises parallax error, an error is necessarily present though it may be very small. Since the parallax errors arise on account of the pointer and the scale not being in the same plane, we can eliminate this error by having the pointer and the scale in the same plane as shown in figure arrangements showing scale and pointer in the same plane'.



Errors due to parallax



Arrangements showing scale and pointer in the same plane

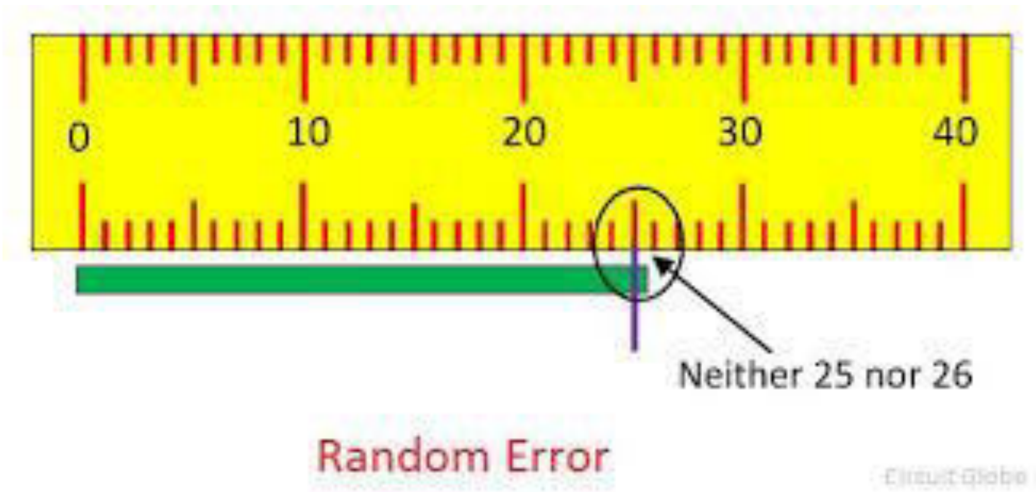
There are human factors involved in measurement. The sensing capabilities of individual observers affect the accuracy of measurement. No two persons observe the same situation in exactly the same way where small details are concerned. For example, there are observational errors in measurements involving timing of an event. One observer may tend to anticipate the signal and read too soon.

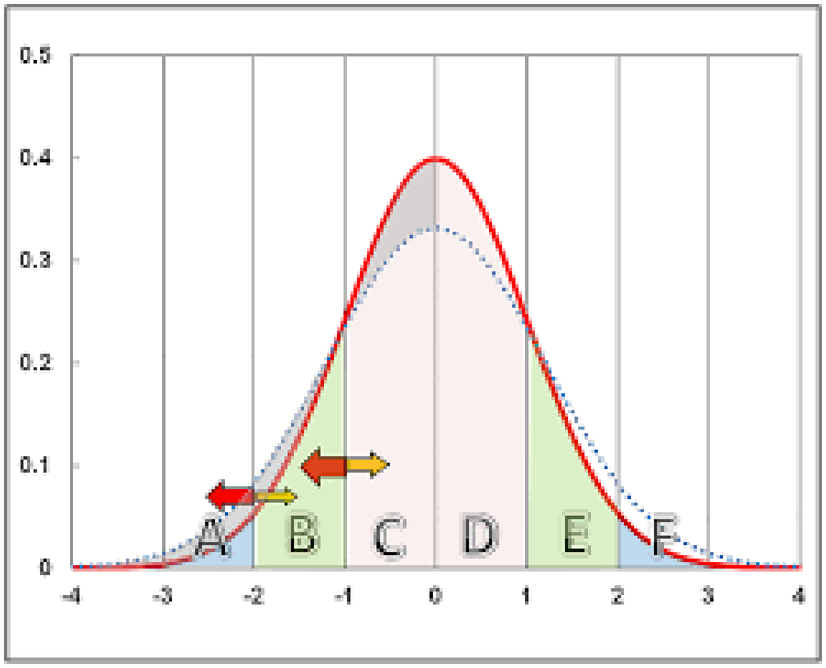
Different experimenters may produce different results, especially when sound and light measurements are involved since no two observers possess the same physical responses. Modern **electrical instruments** have a digital display of output which completely eliminates the errors on account of human observational or sensing powers as the output is in the form of digits.

Random(Residual) Errors

It has been consistently found that experimental results show variation from one reading to another, even after all systematic errors have been accounted for. For example these **types of errors in electrical measuring instruments** are due to a multitude of small factors which change or fluctuate from one measurement to another and are due surely to chance. The quantity being measured is affected by many happenings throughout the universe.

We are aware of and account for some of the factors influencing the measurement, but about the rest we are unaware. The happenings or disturbances about which we are unaware are lumped together and called "Random" or "Residual". Hence the errors caused by these happenings are called ***Random (or Residual) Errors***. Since these type of errors remain even after the systematic errors have been taken care of, we call these errors as ***Residual (Random) Errors***.





In **order to minimize random errors**, the measurements are **repeated several times** and the average (arithmetic mean) value is taken as the correct value of the measured quantity. The mean value would be very close to the most accurate reading. When the number of observation is made 'n' times, the random error reduces to 1/n times.

If a_1, a_2, a_3 ..... a_n are the n different readings of a physical quantity when it is measured, the most accurate value is its arithmetic mean value which is given by

$$a_{mean} = \frac{a_1 + a_2 + a_3 + \ ... a_n}{n} = \frac{1}{n}\sum_{i=1}^{n} a_i$$

SYSTEMATIC ERROR	RANDOM ERROR
Repetitive in Nature	Random in Nature
These errors result from improper conditions and procedures	These errors are inherent in the measuring system
Controlled in magnitude and sense	Accidental in nature and difficult to control
After proper analysis these errors can be reduced or eliminated	Can not be eliminated
Statistical methods does not apply on error	Statistical methods only apply on error
Example: Parallax error, Calibration error, etc.	Slight displacement of measuring joint, friction of mating parts, combined effect etc.

Random errors are statistical fluctuations (in either direction) in the measured data due to the precision limitations of the measurement device. … **Systematic errors**, by contrast, are reproducible inaccuracies that are consistently in the same direction.

References:

[1] P A Marín, M C Bacilio and S J Rosas, Using analog instruments in Tracker video based experiments to understand the phenomena of electricity and magnetism in physics education, Eur. J. Phys. 39 (2018) 035204 (18pp), https://doi.org/10.1088/1361-6404/aaa8f8.

[2] https://circuitglobe.com/measurement-error.html.

[3] https://conjointly.com/kb/measurement-error/#what-is-systematic-error.

[4] https://www.electricalengineeringinfo.com/2016/11/what-different-types-of-errors-in-electrical-measuring-instruments-gross-systematic-random.html

[5] https://www.helpyoubetter.com/measurement-error-and-types-of-errors/

Next slide (DSE-4-(Measurement) Lec-III)

On

Statistical analysis of data