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OPEN AND DISTANCE LEARNING (ODL) PROGRAMMES

(FOR THOSE WHO JOINED THE PROGRAMMES FROM THE ACADEMIC YEAR 2023–2024)

II YEAR

B.Sc. Physics

Course Material

INSTRUMENTATION PHYSICS – I

Prepared

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TEXT BOOKS

1. Albert D. Helfrick and William D. Cooper, Modern Electronic Instrumentation and Measurement Techniques, Prentice-Hall of India Pvt. Limited, Reprint 2002.
2. M. Arumugam, Biomedical Instrumentation, Anuradha Agencies, Reprint 2002.
3. H.S.Kalsi, Electronic Instrumentation, Tata McGraw Hill Education Pvt. Limited, Reprint 2012.

INSTRUMENTATION PHYSICS – I

UNIT-I

MEASUREMENT

Definition - Units of measurement; systems of units - Length, mass, and time measurements - Accuracy and precision

1.1 Definition

Measurement of any physical quantity involves comparison with a certain basic, arbitrarily chosen, internationally accepted reference standard called unit. The result of a measurement of a physical quantity is expressed by a number (or numerical measure) accompanied by a unit. Although the number of physical quantities appears to be very large, we need only a limited number of units for expressing all the physical quantities, since they are interrelated with one another. The units for the fundamental or base quantities are called fundamental or base units. The units of all other physical quantities can be expressed as combinations of the base units. Such units obtained for the derived quantities are called derived units. A complete set of these units, both the base units and derived units, is known as the system of units.

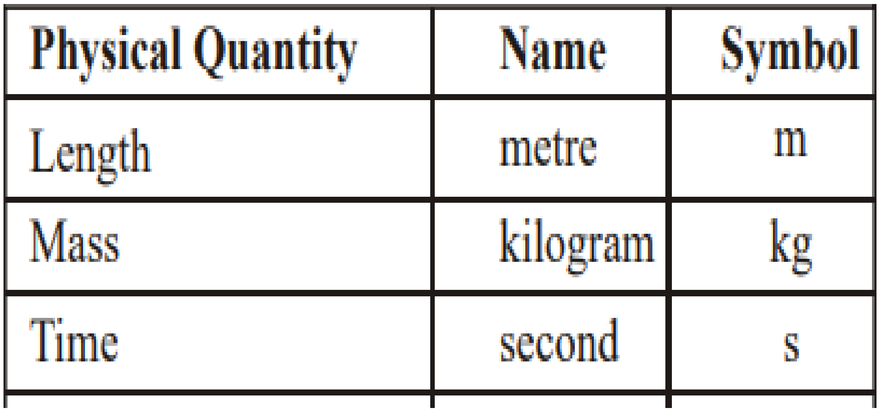
1.2 Systems of units

In earlier time scientists of different countries were using different systems of units for measurement. Three such systems, the CGS, the FPS (or British) system and the MKS system are in use extensively till recently. The base units for length, mass and time in these systems are as follows:

- In CGS system they are centimeter, gram and second respectively.
- In FPS system they are foot, pound and second respectively.
- In MKS system they are metre, kilogram and second respectively.

The system of units which is at present internationally accepted for measurement is the Système International e d' Unites (French for International System of Units), abbreviated as SI. The SI, with standard scheme of symbols, units and abbreviations, developed by the Bureau International des Poids et measures (The International Bureau of Weights and Measures, BIPM) in 1971 were recently revised by the General Conference on Weights and Measures in November 2018. The scheme is now for international usage in scientific, technical, industrial and commercial work. Because SI units used decimal system, conversions within the system are quite simple and convenient.

In this system, there are seven fundamental quantities which are shown below.



Physical Quantity	Name	Symbol
Length	metre	m
Mass	kilogram	kg
Time	second	s

1.3 Accuracy and precision

The accuracy of a number is specified by the number of significant figures it contains. A significant figure is any digit, including zero, provided it is not used to specify the location of the decimal point for the number. For example, the numbers begin or end with zeros,

however, it is difficult to tell how many significant figures are in the number. Consider the number 400. Does it have one (4) or perhaps two (40) or three (400) significant figures?

In order to clarify this situation, the number should be reported using powers of 10. Using engineering notation, the exponent is displayed in multiples of three in order to facilitate conversion of SI units to those having an appropriate prefix. Thus, 400 expressed to one significant figure would be 0.4 (10^3). Likewise, 2500 and 0.00546 expressed to three significant figures would be 2.50 (10^3) and 5.46(10^{-3}).

Zero is not a significant figure when it is the first figure in a number (e.g. 0.00034 has only two significant figures). A zero in any other position is significant (e.g. 102 has three significant figures). In order to avoid confusion it is preferable to use scientific notation when expressing results (e.g. 6.20 × 104 has three significant figures).

- When rounding off numbers, add one to the last figure retained if the following figure is greater than 5 (e.g. 0.53257 becomes 0.5326 when rounded off to four significant figures).

- Round 5 to the nearest even number (e.g. 0.255 becomes 0.26 when rounded off to two significant figure). If the digit just before 5 is even, it is left unchanged (e.g. 0.345 becomes 0.34 when rounded off to two significant figures); if it is odd, its value is increased by one (e.g. 0.335 becomes 0.34 when rounded off to two significant figures).

- If two or more figures are present to the right of the figure to be retained, they are considered as a group (e.g. 6.8 [501] should be rounded off to 6.9; 7.4 [499] should be rounded off to 7.4)

- In addition and subtraction the result should be reported to the same number of decimal places as there are in the number with the smallest number of decimal places.

- In multiplication and division the result should have an uncertainty of the same order as the number with the greatest uncertainty.

- In the logarithm of a number we retain the same number of digits to the right of the decimal point as there are significant figures in the original number.

- In the antilogarithm of a number we retain as many significant figures as there are digits to the right of the decimal point in the original number.

UNIT-II

ERROR

Definition - Types of error (Gross error, Systematic error, Random error) - Statistical analysis (Arithmetic mean, Deviation from the mean, Average deviation, Standard deviation) - Probability of errors (Normal distribution of errors, Probable error) - Limiting errors.

2.1 ERRORS IN MEASUREMENT

The types of errors are follows

i) Gross errors
ii) Systematic errors
iii) Random errors

Gross Errors

The gross errors mainly occur due to carelessness or lack of experience of a human being.

These errors also occur due to incorrect adjustments of instruments these errors cannot be treated mathematically. These errors are also called ‘personal errors’.

Ways to minimize gross errors:

The complete elimination of gross errors is not possible but one ca n minimize them by the following ways:

Taking great care while taking the reading, recording the reading &calculating the result without depending on only one reading, at least three or more readings must be taken preferably by different persons.

Systematic errors

A constant uniform deviation of the operation of an instrument is known as Systematic error. The Systematic errors are mainly due to the short comings of the instrument & the characteristics of the material used in the instrument, such as defective or worn parts, ageing effects, environmental effects, etc.

Types of Systematic errors: There are three types of Systematic errors as:

i) Instrumental errors
ii) Environmental errors
iii) Observational errors

Instrumental errors:

These errors can be mainly due to the following three reasons:

a. **Short coming of instruments**:

These are because of the mechanical structure of the instruments. For example friction in the bearings of various moving parts; irregular spring tensions, reductions in due to improper handling , hysteresis, gear backlash, stretching of spring, variations in air gap, etc .,

Ways to minimize this error: These errors can be avoided by the following methods: Selecting a proper instrument and planning the proper procedure for the measurement recognizing the effect of such errors and applying the proper correction factors calibrating the instrument carefully against a standard

b) Misuse of instruments:

A good instrument if used in abnormal way gives misleading results. Poor initial adjustment, Improper zero setting, using leads of high resistance etc., are the examples of misusing a good instrument. Such things do not cause the permanent damage to the instruments but definitely cause the serious errors.

c) Loading effects

Loading effects due to improper way of using the instrument cause the serious errors. The best ex ample of such loading effect error is connecting a w ell calibrated volt meter across the two points of high resistance circuit. The same volt meter connected in a low resistance circuit gives accurate reading.

Ways to minimize this error: Thus the errors due to the loading effect can be avoided by using an instrument intelligently and correctly.

Environmental errors:

These errors are due to the conditions external to the measuring instrument. The various factors resulting these environmental errors are temperature changes, pressure changes, thermal emf, and ageing of equipment and frequency sensitivity of an instrument Ways to minimize this error: The various methods which can be used to reduce these errors are:

i) Using the proper correction factors and using the information supplied by the manufacturer of the instrument

ii) Using the arrangement which will keep the surrounding conditions Constant

iii) Reducing the effect of dust, humidity on the components by hermetically

sealing the components in the instruments

iv) The effects of external fields can be minimized by using the magnetic or electro static shields or screens

v) Using the equipment which is immune to such environmental effects. Observational errors: These are the errors introduced by the observer. These are many sources of observational errors such as parallax error while reading a meter, wrong scale selection, etc.

Ways to minimize this error To eliminate such errors one should use the instruments with mirrors, knife edged pointers, etc. The systematic errors can be subdivided as static and dynamic errors. The static errors are caused by the limitations of the measuring device while the dynamic errors are caused by the instrument not responding fast enough to follow the changes in the variable to be measured.

Random errors

Some errors still result, though the systematic and instrumental errors are reduced or at least accounted for. The causes of such errors are unknown and hence the errors are called random errors.

Ways to minimize this error The only way to reduce these errors is by increasing the number of observations and using the statistical methods to obtain the best approximation of the reading

2.2 Statistical analysis

Arithmetic mean:

Arithmetic Mean, often referred to simply as the mean or average, is a measure of central tendency used to summarize a set of numbers.

Arithmetic Mean OR (AM) is calculated by taking the sum of all the given values and then dividing it by the number of values. For evenly distributed terms arranged in ascending or descending order arithmetic mean is the middle term of the sequence. The arithmetic mean is sometimes also called mean, average, or arithmetic average.

Properties of Arithmetic Mean:

Arithmetic Mean has various Properties and some of the important properties of the arithmetic mean are discussed below. If we take "n" observations, i.e. x_1, x_2, x_3, ….,x_n and let $\bar{x}$ be its arithmetic mean then,

- If all the values in the data set are equal then the arithmetic mean of the data set is the individual value of the data set.
- The sum of the deviation of all the values in a set of observations from the arithmetic mean is zero.
- If we increase or decrease all the values of the data set by a fixed value then the arithmetic is increased or decreased by the same value.
- If we multiply or divide all the values of the data set by a fixed value then the arithmetic is multiplied or divided by the same value.

Deviation from the mean:

Mean Deviation (also called average deviation) is the average of deviations of items of a series taken from mean or mode or median. It means, it can be calculated based on the arithmetic average, mode or median. A peculiarity of this measure is that all the deviations are known and placed in the form of positive units.

The deviations, however, may be positive or negative, but so far as the calculation of mean deviation is concerned, they all are considered as positive. Thus, it can be said that a mean deviation is an average of the second order measured from mean, median, or mode and considering all the deviations as positive.

Most statisticians agree to the fact that out of all the measures of mean deviation, the best results are obtained if the mean deviation is calculated based on the value of the median. However, it can also be calculated based on the mean and the mode. In this connection it is important that unless specifically mentioned, mean deviation should be calculated based on the median or mean.

Advantages of Mean Deviation:

It takes into consideration all the items of the series.

Hence, result arrived at are sufficiently representative. The positive deviations taken into consideration simplify calculations.

Flexibility in calculations as it can be calculated on the basis of values of mean, mode or median. Results are not affected by the extreme items.

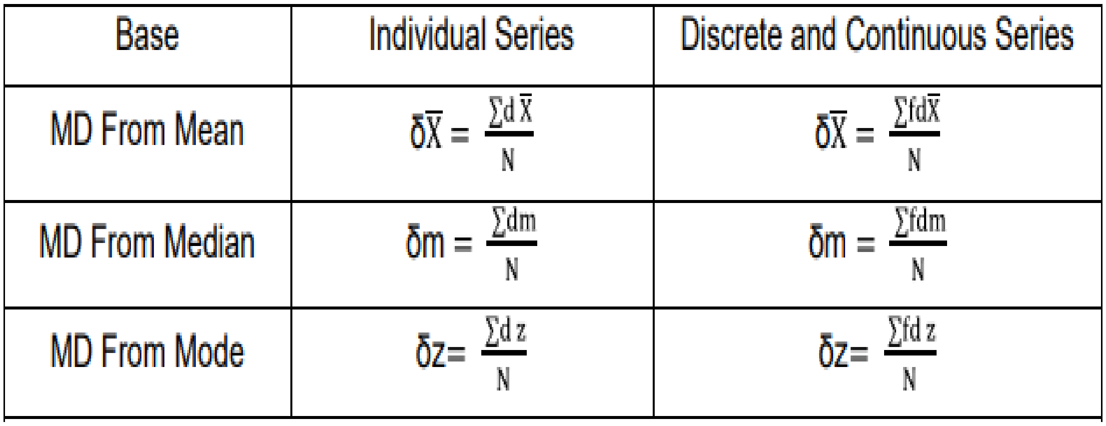
It is very easy to calculate and follow.

Disadvantages of the Mean Deviation:

Taking all the deviations as positive is not mathematically correct.

The results arrived at are always far from truth.

This method is not considered as useful for making comparisons, either of the series itself or of the structure of the series.



Base	Individual Series	Discrete and Continuous Series
MD From Mean	$\delta\overline{X} = \frac{\sum d\overline{X}}{N}$	$\delta\overline{X} = \frac{\sum fd\overline{X}}{N}$
MD From Median	$\delta m = \frac{\sum dm}{N}$	$\delta m = \frac{\sum fdm}{N}$
MD From Mode	$\delta z = \frac{\sum dz}{N}$	$\delta z = \frac{\sum fdz}{N}$

Standard deviation:

The standard deviation is the most commonly used measure of dispersion. It may be defined as the square root of the average of the squares of the deviations of the observations from the arithmetic mean of the distribution.

Calculations of standard deviation are invariably based on the arithmetic mean. This measure of dispersion is given the name of standard because, firstly, it is based on an algebraically correct method, and secondly, it may be used for further statistical treatment.

For example, the variance and the coefficient of variance may be ascertained directly from the value of the standard deviation.

Characteristics of the Standard Deviation:

It is mathematically correct because it considers all the deviations are with their proper algebraically signs.

As it is based on the value of mean only, it gives uniform and accurate results.

The standard deviation is always a positive digit.

Merits of Standard Deviation:

It is rigidly defined. Its value is always definite.

It considers all observations of the series.

It is capable of further algebraic treatment.

It is less affected by the fluctuations of sampling. It is easy to calculate and readily understood.

Demerits of Standard Deviation:

It takes into consideration all the items of the series.

So, the heterogeneous items may get un-due weight.

Its scope is limited because it is difficult to understand.

The process of squaring the deviations and then to find the value of its square root is a time consuming affair.

It is quite difficult also.

2.3 Probability of errors

Normal distribution of errors:

Normal distribution, also known as the Gaussian distribution, is a probability distribution that is symmetric about the mean, showing that data near the mean are more frequent in occurrence than data far from the mean.

The normal distribution appears as a "bell curve" when graphed.

Properties of Normal Distribution

The normal distribution is the most common type of distribution assumed in technical stock market analysis.

The standard normal distribution has two parameters: the mean and the standard deviation. In a normal distribution, mean (average), median (midpoint), and mode (most frequent observation) are equal.

These values represent the peak or highest point. The distribution then falls symmetrically around the mean, the width of which is defined by the standard deviation.

The normal distribution model is key to the Central Limit Theorem (CLT) which states that averages calculated from independent, identically distributed random variables have approximately normal distributions, regardless of the type of distribution from which the variables are sampled.

The normal distribution is one type of symmetrical distribution. Symmetrical distributions occur when a dividing line produces two mirror images. Not all symmetrical distributions are normal since some data could appear as two humps or a series of hills in addition to the bell curve that indicates a normal distribution.

Probable error:

Probable Error is basically the correlation coefficient that is fully responsible for the value of the coefficients and its accuracy**.**

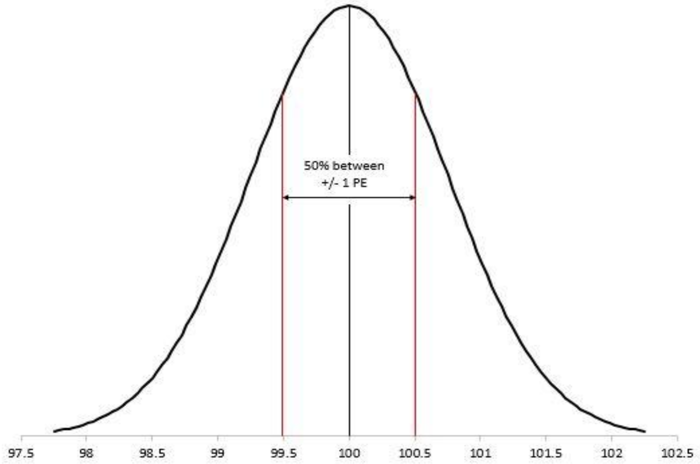


Figure 1.1. Bell curve

As mentioned, probable error is the coefficient of correlation that supports in finding out about the accurate values of the coefficients. It also helps in determining the reliability of the coefficient.

The calculation of the correlation coefficient usually takes place from the samples. These samples are in pairs. The pairs generally come from a very large population.

It is quite an easy job to find out about the limits and bounds of the correlation coefficient.

The correlation coefficient for a population is usually based on the knowledge and the sample relating to the correlation coefficient. Therefore, probable error is the easy way to find out or obtain the correlation coefficient of any population. Hence, the definition is:

Probable Error $= 0.674 \times 1 - r^2 / \sqrt{N}$

Here, r = correlation coefficient of ‘n’ pairs of observations for any random sample and

N = Total number of observations.

2.4 Limiting errors:

Manufacturers of any equipment give guarantee about the accuracy of the equipment with some limiting deviations from the specified accuracy.

Most of the measuring instruments are guaranteed for their accuracy with a percentage deviation of full scale reading.

This limiting deviation from the specified values are called the limiting error or guarantee error.

For example, if the pressure of pressure gauge is specified as 100 $kN/m^2 \pm 1\%$, the pressure of the gauge may have any value between 90 kN/m^2 to 110 kN/m^2 .

UNIT-III

ELECTRODES

Electrode potential - Purpose of the electrode paste - Electrode material - Types of electrodes - Microelectrodes (metal microelectrode) - Surface electrodes

3.1 ELECTRODES

Electrodes are devices that convert ionic potentials into electronic potentials. The type of electrode used for the measurements depends on the anatomical In order to process the signal in electronic circuits, it will be better to convert ionic conduction into electronic conduction.

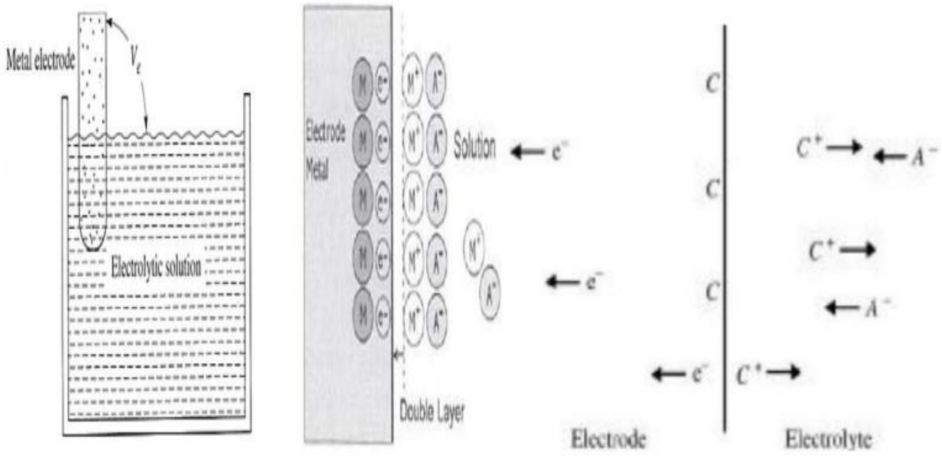


Figure. 3.1. Electrodes

3.2 Electrode Theory

To measure bioelectric potentials, a transducer is required. Electrical signals produced by various body activities are used in monitoring / diagnosis.

In order to measure and record potentials and, hence, currents in the body, it is necessary to provide some interface between the body and the electronic measuring apparatus. Bio carry out this interface function.

- A transducer consists of two electrodes, which measure ionic potential difference between two points.

- The designation of the Bio potential waveform ends with “Gram”. The name of the instrument bio potential normally ends with “Graph”. Propagation of action potential through different body tissues produces final waveform recorded by electrodes

- Electrical activity is explained by differences in ion concentrations within the body (sodium, Na+; chloride, Cl–; potassium, K+). A potential difference (voltage) occurs between 2 points with different ionic concentrations

- Propagation of action potential through different bod electrodes

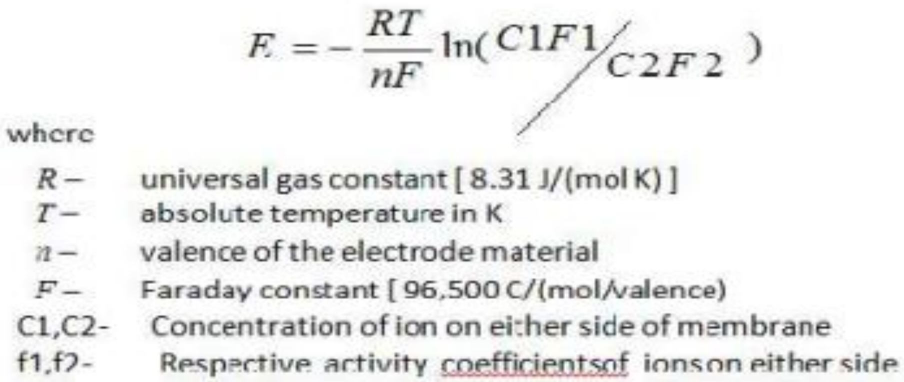
- Electrical activity is explained by differences in ion concentrations within the body (sodium, Na^+; chloride, Cl^-; potassium, K^+). A potential difference (voltage) occurs between 2 points with difionic concentrations.

Nernst Relation

It can be shown that an electric potential E will exist between the solutions on either side of the membrane, based upon the relative activity of the permeable ions in each of these solutions. This relationship is known as the Nernst equation.

The relationship between the ionic concentration (activity) and the electrode potential is given by the Nernst equation:

When no electric current flows between an electrode and the solution of its ions or across an ion permeable membrane, the potential observed should be the half Nernst potential, respectively. If, however, there is a current, these potentials can be altered.



$$E = -\frac{RT}{nF}\ln\left(C1F1 / C2F2\right)$$

where

R – universal gas constant [8.31 J/(mol K)]

T – absolute temperature in K

n – valence of the electrode material

F – Faraday constant [96,500 C/(mol/valence)

C1,C2- Concentration of ion on either side of membrane

f1,f2- Respective activity coefficientsof ionson either side

3.3 Equivalent circuit for bio-potential electrode

- Where R_d and C_d are components that represent the impedance associated with the electrodeelectrolyte interface and polarization at this interface.

- R_s is the series resistance associated with electrode materials.

- The battery Ehc represents the half -cell potential

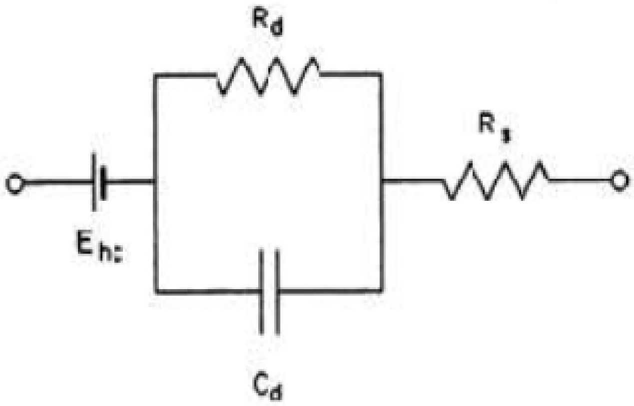
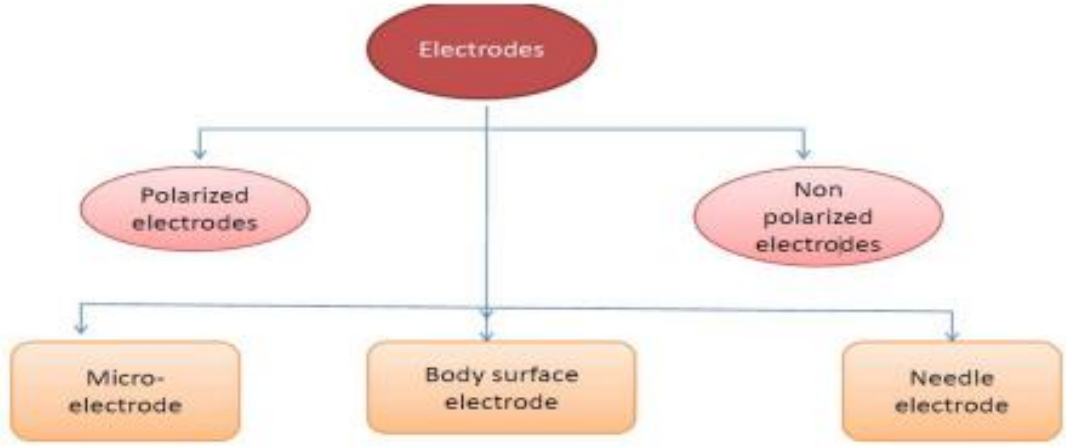


Figure. 3.2 Equivalent circuit

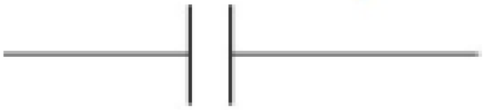
3.4 Classification of Electrodes

Electrode is an interface to connect the measurement devices and measure bioelectrical potentials, electrode is used as an interface.



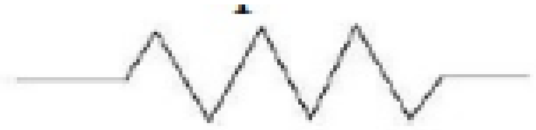
Perfectly Polarizable Electrodes

Perfectly polarizable electrodes are those in which no actual charge crossing the electrode – electrolyte interface when a current is applied. There has to be current across the interface and the electrode behaves as though it were a capacitor.



Perfectly Non -Polarizable Electrodes or Perfectly Reversible

Perfectly non-polarizable electrodes are those in which current passes freely across the electrode electrolyte interface, requiring no energy to make the transition. Thus, for perfectly non-polarizable electrodes there are no overpotentials. – Electrode interface impedance is represented as a potential electrode are components that represent resistor.



Limb Electrodes

Limb leads are made up of 4 leads placed on the extremities: left and right wrist; left and right ankle. The lead connected to the right ankle is a neutral lead, like you would find in an electric there to complete an electrical circuit. The limb electrodes plays role in the ECG.

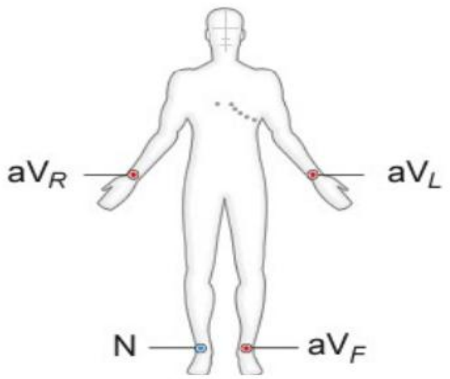


Figure 3.3 Limb electrode

3.5 Micro Electrodes

Microelectrodes are electrodes with tips having tips sufficiently small enough to penetrate a single cell in order to obtain readings from within

- The tip must be small enough to permit penetration without damaging the minute cell.
- The main functions of microelectrodes are potential recording and current injection.

- Microelectrodes are having high impedances in mega ohm range because of their smaller size.

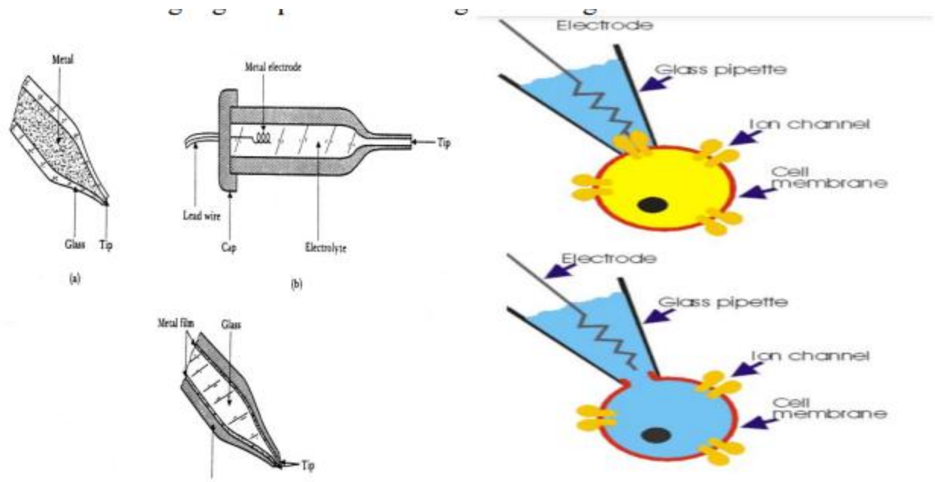


Figure 3.4 Micro electrode

Types

- Metal microelectrode
- Micropipette

Metal microelectrode

Metal microelectrodes are formed by electrolytically etching the tip of fine tungsten to the desired size and dimension. Then the wire is coated almost to the tip with any type of insulating material.

The metal-ion interface takes place where the metal tip contacts the electrolyte Limb leads are made up of 4 leads placed on the extremities: left and right wrist; left and right ankle. The lead connected to the right ankle is a neutral lead, like you would find in an electric circuit.

Micropipette

The micropipette type of microelectrode is a glass micropipette with its tip drawn out to the desired size

The micropipette is filled with an electrolyte which should be compatible with the cellular fluids A micropipette is a small and extremely fine pointed pipette used in making microinjection.

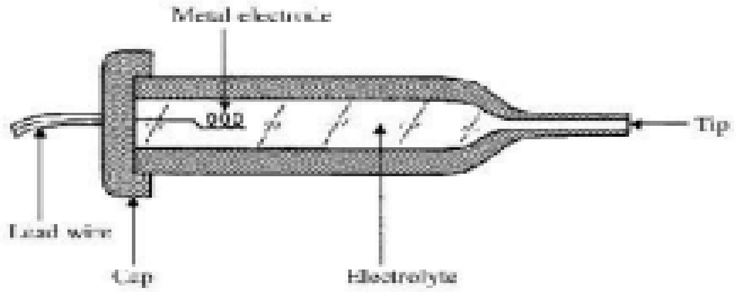


Figure 3.5 Micropipette

3.6 Surface Electrodes

Surface electrodes are those which are placed in contact with the skin of the subject in order to obtain bioelectric potentials from the surface.

Body surface electrodes are of many sizes and types. In spite of the type, any surface electrode can be used to sense ECG, EEG, EMG etc.

Immersion electrodes

They are one of the first type of bioelectric measuring electrodes. Immersion electrodes were simply bucketing of saline and feet. So, it was not a comfortable type of measurement and hence it was replaced with plate electrodes.

Plate electrodes

The plate electrodes have generally smaller contact area and they do not totally seal on the patient.

- The electrode slippage and displacement of plates were the major difficulties faced by these types of electrodes because they have a tendency to lose their adhesive ability as a result of contact with fluids on or near the patient.

- Since these types of electrodes were very sensitive, it led to measurement errors

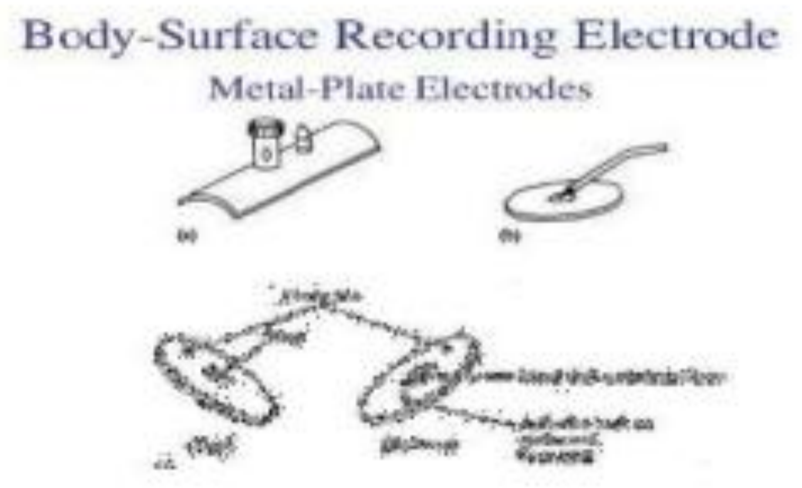


Figure 3.6 Body surface recording electrode

Disposable electrodes

Normally plate electrodes, floating electrodes etc can be used more than one time.

- This requires the cleaning and cares after each use.

- We can use disposable electrodes which can be used only once and be disposed.

- These types of electrodes are now widely used

Figure 3.7 Disposal electrodes

Suction electrodes

These types of electrodes are well suited for the attachment to flat surfaces of body and to regions where the under lying tissue is soft, due to the presence of contact surface.

- An advantage of these types of electrodes is that it has a small surface area

These types of electrodes are mainly used for the measurement of ECG.

- Suction electrodes used a plastic syringe barrel to house suction tubing and input cables to an AC amplifier

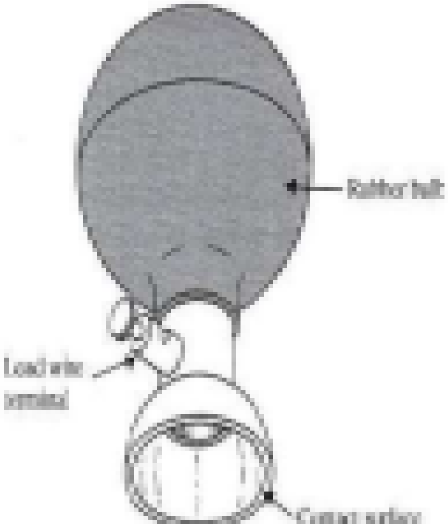


Figure 3.8 Disposal electrodes

Ear clip & Scalp electrodes:

These types of electrodes are widely used

- Scalp electrodes can provide EEG easily by placing it over bare head. A typical ear clip electrode is shown in Fig. 3.9. The most common method for EEG measurement is, here we use scalp electrode usually. They can avoid measurement errors and movement errors.

During labour internal monitoring may be needed and is usually in the form of an electrode placed under the baby's scalp. It is called fatal scalp electrode which is used to monitor baby's heartbeat while still in uterus.

Figure 3.9 Scalp electrodes

UNIT-IV

SPECIALIZED IN MEDICAL INSTRUMENTS

Angiography - Digital thermometer - Endoscopes - EEG - ECG – Computed Tomography (CT scan)

4.1 Angiography

Fluorescein Angiography (FA) is a diagnostic procedure that uses a special camera to record the blood flow in the RETINA – the light sensitive tissue at the back of the eye. The test does not involve any direct contact with the eyes. Your eyes will be dilated before the procedure.

Fluorescein dye is injected into a vein in the arm/hand. As dye passes through the blood vessels of your eye, photographs are taken to record the blood flow in your retina. The photographs can reveal abnormal blood vessels or damage to the lining underneath the retina.

The images will be captured in black and white. The dye will fluoresce in the blood vessels and be recorded as light grey or white in the image. Interpretation of the abnormal angiogram relies on the identification of areas that exhibit hypo fluorescence (darkness) or hyper fluorescence (brightness).

4.2 Digital thermometer:

Digital thermometer consists of a resistor such as a thermistor or RTD and a computing mechanism that measures temperature by converting resistance variations into readable values. They require an ADC to convert analog signals to digital numbers for display.

- Various digital thermometers are used for medical, culinary, and industrial applications. They provide accurate and safe measurements with features like quick readouts, alarms, and memory functions, offering greater convenience and safety compared to traditional mercury or dial thermometers.
- Proper use and maintenance of digital thermometer work are crucial for accurate measurements. Users should follow instructions, maintain hygiene, and ensure correct

probe placement, along with caring for the device by cleaning and storing it correctly to maintain its integrity and accuracy.

To understand how digital thermometers work, it is essential to know that at its core, a digital thermometer is a simple device. It primarily consists of a small computing mechanism, and a resistor, often a thermistor or a resistance temperature detector (RTD). These components work harmoniously together to detect temperature changes and convert them into readable values.

The sensor, which is the heart of the thermometer, detects changes in temperature as variations in resistance.

The computing mechanism interprets this resistance variation and converts it into a readable temperature value. It's interesting to note that advancements in technology have allowed for the production of high-quality digital thermometers at a relatively low cost, thanks to the affordability of good thermistors. Understanding how digital thermometers work is essential for accurate temperature readings.

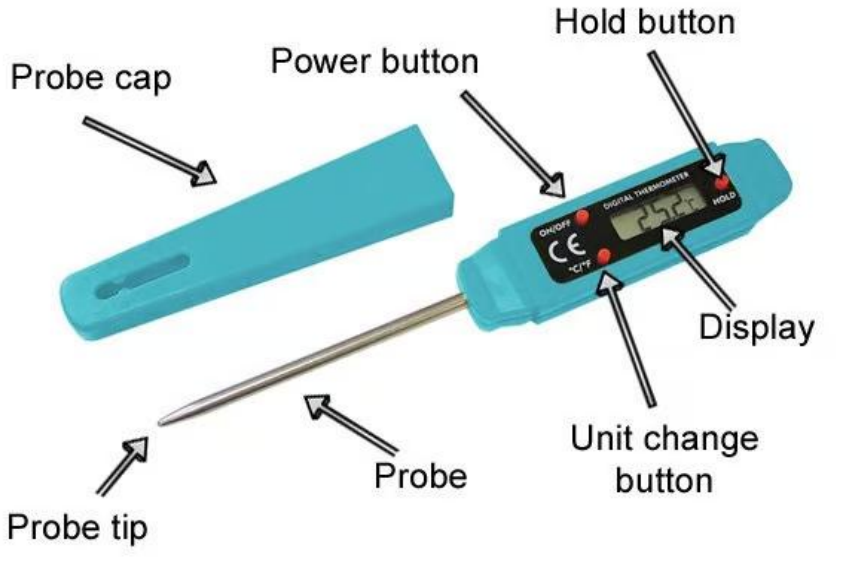


Figure 4.1 Digital thermometer

Digital thermometers use a variety of sensors to measure temperature, including:

- Thermocouples
- Resistance Temperature Detectors (RTDs)
- Thermistors
- Solid-state sensors

These sensors produce an analog signal, such as voltage, current, or a change in resistance, in response to temperature fluctuations.

Negative Temperature Coefficient (NTC) thermistors and Positive Temperature Coefficient (PTC) devices, specific types of semiconductor devices, enhance sensitivity and response times in detecting temperature.

Thermistors, a kind of resistor, non-linearly adjust their resistance with each increase in temperature, resulting in precise temperature measurements. Meanwhile, solid-state sensors produce a small, linear voltage that accurately reflects temperature changes. Manufacturers provide tables or mathematical calculations that enable effective utilization of these sensors.

In a nutshell, applying a voltage across a probe enables the measurement of current flow; this current reflects the level of resistance, which a microchip then converts into a temperature reading.

Ensuring Accuracy in Digital Thermometer Work

The accuracy of a digital thermometer is significantly influenced by:

- Its design and construction
- The quality of the materials used
- A high-quality sensor
- Other quality parts
- A well-designed housing

When combined, these factors produce a digital thermometer that delivers highly reliable readouts.

4.3 Endoscopy

- Endoscopy is a nonsurgical procedure used to examine a person's digestive tract.
- Using an endoscope, a flexible tube with a light and camera attached to it, your doctor can view pictures of your digestive tract on a colour TV monitor.
- Endoscopy is the insertion of a long, thin tube directly into the body to observe an internal organ or tissue in detail. It can also be used to carry out other tasks including imaging and minor surgery.
- Endoscopes are minimally invasive and can be inserted into the openings of the body such as the mouth or anus.
- Alternatively, they can be inserted into small incisions, for instance, in the knee or abdomen. Surgery completed through a small incision and assisted with special instruments, such as the endoscope, is called keyhole surgery.
- Because modern endoscopy has relatively few risks, delivers detailed images, and is quick to carry out.

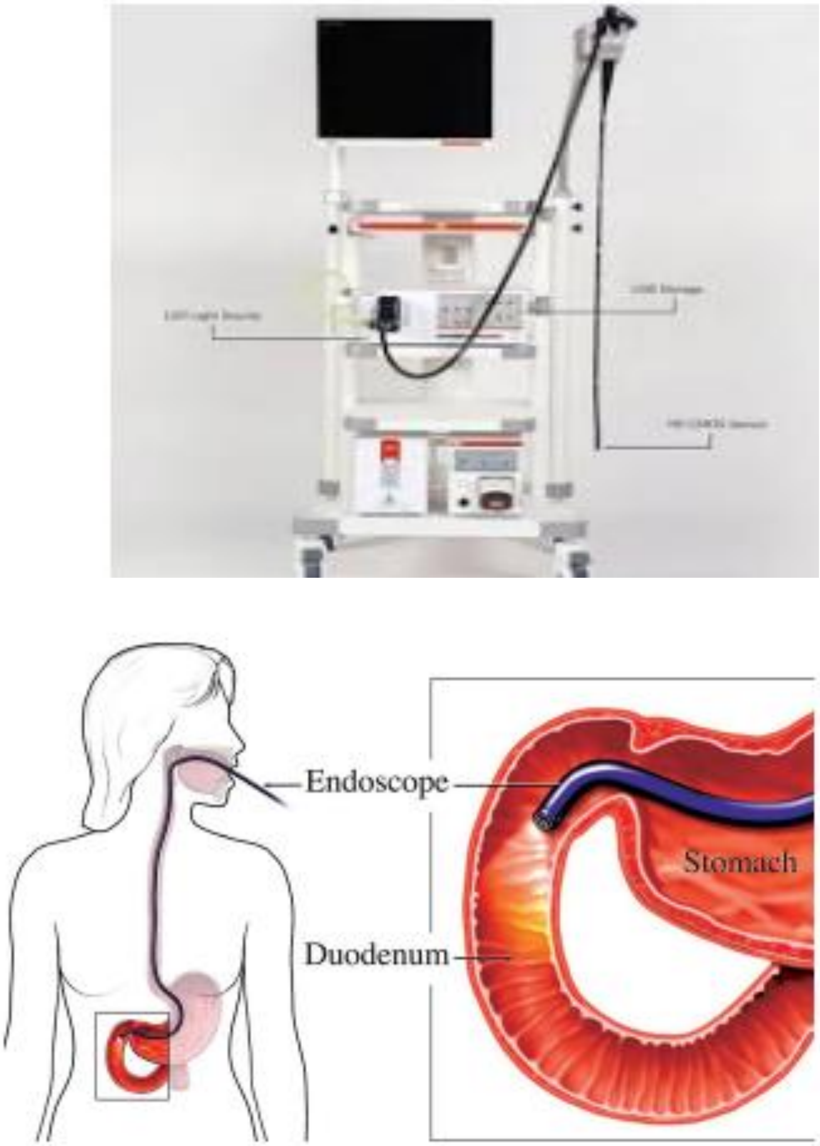


Figure 4.2 Endoscopy

An endoscope consist of:

- A rigid or flexible tube.
- A light delivery system to illuminate the organ or object under inspection. The light source is normally outside the body and the light is typically directed via an optical fiber system.

- A lens system transmitting the image from the objective lens to the viewer, typically a relay lens system in the case of rigid endoscopes or a bundle of fiber optics in the case of a fiberscope. an eyepiece. Modern instruments may be video scopes, with no eyepiece. A camera transmits image to a screen for image capture.

- An additional channel to allow entry of medical instruments or manipulators. The endoscope also has a channel through which surgeons can manipulate tiny instruments, such as forceps, surgical scissors, and suction devices.

- A variety of instruments can be fitted to the endoscope for different purposes.

- A surgeon introduces the endoscope into the body either through a body opening, such as the mouth or the anus, or through a small incision in the skin

- Although fibre-optic endoscopes can be used to visualize the stomach and duodenum, they are unable to reach farther into the small intestine.

- As a result, examination of the small intestine may require the use of wireless capsule endoscopy (video capsule endoscopy), which consists of a pill-sized camera that is swallowed. The camera transmits data to sensors that are attached to the abdomen with adhesive, and a data recorder that stores image information collected by the camera is attached to a belt worn around the waist, the sensors and belt are worn for a period of eight hours, during which time the camera capsule obtains images of nearly the entire length of the small intestine. The images stored in the data recorder are downloaded onto a computer for analysis. The capsule eventually travels the length of the gastrointestinal tract and is excreted in a bowel movement.

4.4 ELECTROENCEPHALOGRAPH (EEG):

- Electroencephalograph is an instrument for recording the electrical activity of the brain, by suitably placing surface electrodes on the scalp. EEG, describing the general function of the brain activity, is the superimposed wave of neuron potentials operating in a non-synchronized manner in the physical sense. Its stochastic nature originates just from this, and the prominent signal groups can be empirically connected to diagnostic conclusions.

- Monitoring the electroencephalogram has proven to be an effective method of diagnosing many neurological illnesses and diseases, such as epilepsy, tumour, cerebrovascular lesions, ischemia and problems associated with trauma. It is also effectively used in the operating room to facilitate anaesthetics and to establish the integrity of the anaesthetized patient's nervous system. This has become possible with the advent of small, computer-based EEG analysers.

- EEG may be recorded by picking up the voltage difference between an active electrode on the scalp with respect to a reference electrode on the ear lobe or any other part of the body. This type of recording is called 'monopolar' recording. However, 'bipolar' recording is more popular wherein the voltage difference between two scalp electrodes is recorded. Such recordings are done with multi-channel electroencephalographs.

EEG signals picked up by the surface electrodes are usually small as compared with the ECG signals. They may be several hundred microvolts, but 50 microvolts peak-to-peak is the most typical. The brain waves, unlike the electrical activity of the heart, do not represent the same pattern over and over again. Therefore, brain recordings are made over a much longer interval of time in order to be able to detect any kind of abnormalities.

- Selecting the proper filter band (band width must be at least 0.5 Hz–70 Hz) is important to acquire proper signal. This is important for digitizing and data storing. Sufficient and optimum sampling rate (140 Hz) should be adopted.

- EEG electrodes are smaller in size than ECG electrodes. They may be applied separately to the scalp or may be mounted in special bands, which can be placed on the patient's head. In either case, electrode jelly or paste is used to improve the electrical contact. If the electrodes are intended to be used under the skin of the scalp, needle electrodes are used. They offer the advantage of reducing movement artefacts. EEG electrodes give high skin contact impedance as compared to ECG electrodes. Good electrode impedance should be generally below 5 kilohms.

- Impedance between a pair of electrodes must also be balanced or the difference between them should be less than 2 kilohms. EEG preamplifiers are generally designed to have a very high value of input impedance to take care of high electrode impedance.

- In today’s technology, high input impedance (1 G) amplifier chips and active electrode approaches decrease dependency of the contact impedance. To acquire proper signal, electrodes should not be moved. Otherwise, it causes fluctuation of the EEG signal, and spikes on it.

- Noise reduction techniques must be considered in electronic circuitry and printed circuit board design. Electronic cards and connection cables should be placed in a metal box to reduce electronic noise as much as possible. Using twisted, blended, and driven signal cables gives good results. Because EEG signals are of low amplitude, they are very sensitive to electronic noise.

- Electronic noise should be less than 2 μV (peak-to-peak).

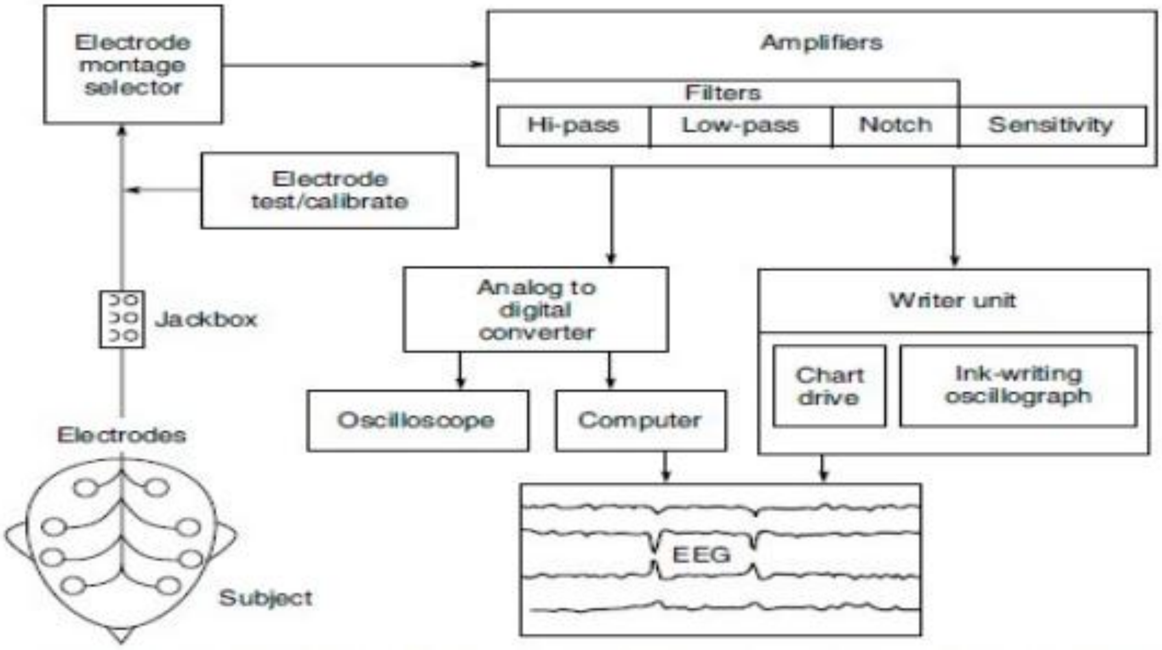


Figure 4.3 Block diagram of recording the electrical activity of the brain

EEG Uses

EEGs are used to diagnose conditions like:

- Brain tumors
- Brain damage from a head injury
- Brain dysfunction from various causes (encephalopathy)
- Inflammation of the brain (encephalitis)
- Seizure disorders including epilepsy
- Sleep disorders
- Stroke An EEG may also be used to determine if someone in a coma has died or to find the right level of anesthesia for someone in a coma.

4.5 Electrocardiogram ECG

- An ECG, also sometimes referred to as an EKG from the original German word ‘electrocardiogram’, measures the electrical activity of the heart. This electrical activity produces the contractions and relaxations of the cardiac muscles required to pump blood around the body.
- An ECG is recorded over a series of cardiac cycles (heartbeats) and shows the different phases of the cardiac cycle.
- The ECG indirectly measures transmembrane voltages in myocardial cells that depolarize and repolarize within each cardiac cycle. These depolarizations and repolarization events produce ionic currents within the body, and these are transduced into voltages by electrodes placed on the surface of the chest and thorax Up to twelve different lead voltages are recorded, with the magnitude of the voltages being in the low mV range, and a frequency spectrum between 0 and 30 Hz.

- The ECG signal has many distinct features, such as the P-wave, QRS-complex and T-wave. The amplitude, shape and relative timing of these features can be used to diagnose different clinical conditions.

- An ECG is an essential part of diagnosing and treating patients with acute coronary syndromes and is the most accurate method of diagnosing ventricular conduction disturbances and cardiac arrhythmias.

It is also used to diagnose heart conditions such as myocardial infarcts, atrial enlargements, ventricular hypertrophies and blocks of the various bundle branches. An ECG is universally used to monitor a patient's cardiac activity during surgery.

- Most ECG machines are now digital and automated, meaning that the data is analysed automatically. Software algorithms measure different aspects (such as delays, durations and slopes) of the ECG waveform and provide a set of keyword interpretations of the scan such as 'abnormal ECG' or more specific suggested diagnoses such as 'possible sinoatrial malfunction'

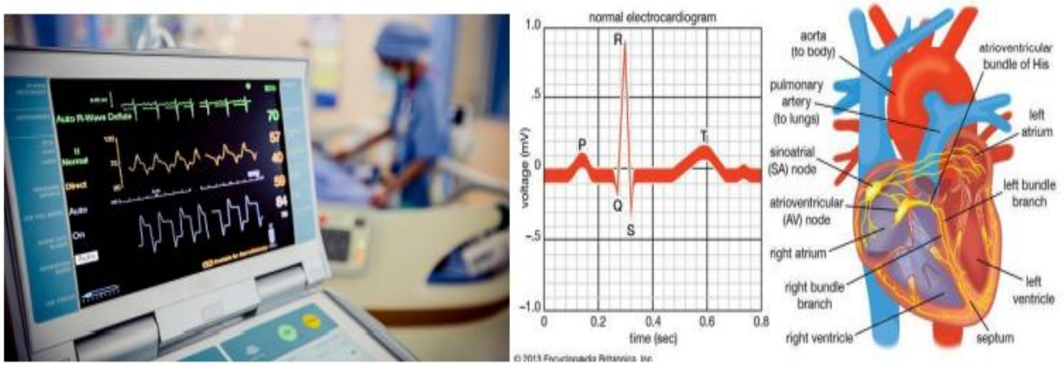


Figure 4.4 Recording of ECG

Block diagram Description of an Electrocardiograph

The potentials picked up by the patient electrodes are taken to the lead selector switch. In the lead selector, the electrodes are selected two by two according to the lead program. By means of capacitive coupling, the signal is connected symmetrically to the long-tail pair differential preamplifier.

The preamplifier is usually a three or four stage differential amplifier having a sufficiently large negative current feedback, from the end stage to the first stage, which gives a stabilizing effect. The amplified output signal is picked up single-ended and is given to the power amplifier.

The power amplifier is generally of the push-pull differential type. The base of one input transistor of this amplifier is driven by the preamplifier unsymmetrical signal.

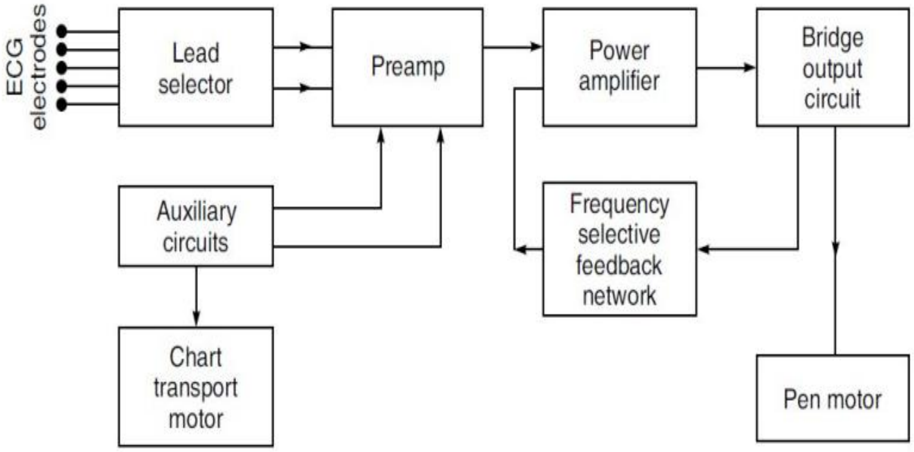


Figure 4.5 Block diagram of ECG

The base of the other transistor is driven by the feedback signal resulting from the pen position and connected via frequency selective network. The output of the power amplifier is single-ended and is fed to the pen motor, which deflects the writing arm on the paper.

A direct writing recorder is usually adequate since the ECG signal of interest has limited bandwidth. Frequency selective network is an R–C network, which provides necessary damping of the pen motor and is pre-set by the manufacturer.

The auxiliary circuits provide a 1 mV calibration signal and automatic blocking of the amplifier during a change in the position of the lead switch. It may include a speed control circuit for the chart drive motor.

A ‘standby’ mode of operation is generally provided on the electrocardiograph. In this mode, the stylus moves in response to input signals, but the paper is stationary. This mode allows the operator to adjust the gain and baseline position controls without wasting paper.

4.6 COMPUTED TOMOGRAPY

Limitations of X-rays

1. The super-imposition of the three-dimensional information onto a single plane makes diagnosis confusing and often difficult.

2. The photographic film usually used for making radiographs has a limited dynamic range and, therefore, only objects that have large variations in X-ray absorption relative to their surroundings will cause sufficient contrast differences on the film to be distinguished by the eye. Thus, whilst details of bony structures can be clearly seen, it is difficult to discern the shape and composition of soft tissue organs accurately.

3. In such situations, growths and abnormalities within tissue only show a very small contrast difference on the film and consequently, it is extremely difficult to detect them, even after using various injected contrast media.

4. The problem becomes even more serious while carrying out studies of the brain due to its overall shielding of the soft tissue by the dense bone of the skull.

Basic Principle of CT

- In computed tomography (CT), the picture is made by viewing the patient via X-ray imaging from numerous angles, by mathematically reconstructing the detailed structures and displaying the reconstructed image on a video monitor.

- Computed tomography differs from conventional X-ray techniques in that the pictures displayed are not photographs but are reconstructed from a large number of absorption profiles taken at regular angular intervals around a slice, with each profile being made up from a parallel set of absorption values through the object.

- In computed tomography, X-rays from a finely collimated source arc made to pass through a slice of the object or patient from a variety of directions. For directions along which the path.

length through-tissue is longer, fewer X-rays are transmitted as compared to directions where there is less tissue attenuating the X-ray beam. In addition to the length of the tissue traversed, structures in the patient such as bone may attenuate X-rays more than a similar volume of less dense soft tissue.

- In principle, computed tomography involves the determination of attenuation characteristics for each small volume of tissue in the patient slice, which constitute the transmitted radiation intensity recorded from various irradiation directions. It is these calculated tissue attenuation characteristics that actually compose the CT image. For a monochromatic X-Ray beam, the tissue attenuation characteristics can be described by,

$$I_t = I_o e^{j\mu x}$$

Where,

I_o = Incident radiation intensity

I_t = Transmitted intensity

X= Thickness of tissue

μ = Characteristic attenuation coefficient of tissue If a slice of heterogeneous tissue is irradiated given below, and we divide the slice into volume elements or voxels with each voxel having its own attenuation coefficient, it is obvious that the sum of the voxel attenuation coefficients for each X-ray beam direction can be determined from the experimentally measured beam intensities for a given voxel width. However, each individual voxel attenuation coefficient remains unknown.

Computed tomography uses the knowledge of the attenuation coefficient sums derived from X-ray intensity measurements made at all the various irradiation directions to calculate the attenuation coefficients of each individual voxel to form the CT image

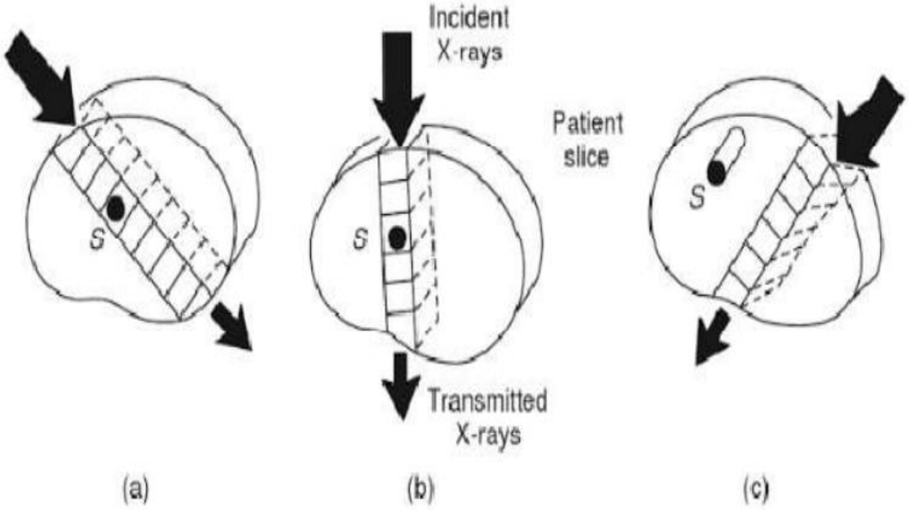


Figure 4.6 Computed tomography

Block Diagram of the CT System

The X-ray source and detectors are mounted opposite each other in a rigid gantry with the patient lying in between, and by moving one or both of these around and across the relevant sections, which is how the measurements are made.

- The X-ray tube and the detector are rigidly coupled to each other. The system executes translational and rotational movement and trans radiates the patient from various angular projections. With the aid of collimators, pencil thin beam of X-ray is produced.

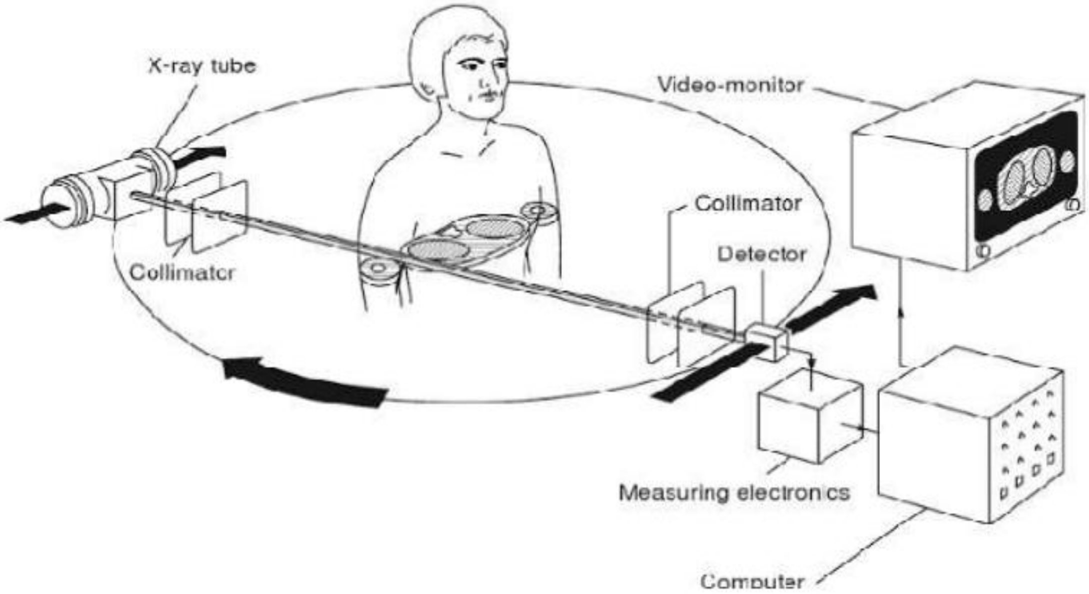


Figure 4.7 CT System

- A detector converts the X-radiation into an electrical signal. Measuring electronics then amplify the electrical signals and convert them into digital values. A computer then processes these values and computes them into a matrix-line density distribution pattern which is reproduced on a video monitor as a pattern of grey shade.

- In one system which employs 18 traverses in the 20s scanning cycle, 324,000 (18 x 30 x 600) X-ray transmission readings are taken and stored by the computer. These are obtained by integrating the outputs of the 30 detectors with approximately 600 position pulses.

- The position pulses are derived from a glass graticule that lies between a light emitting diode and photo-diode assembly that moves with the detectors. The detectors are usually sodium iodide crystals, which are thallium-doped to prevent an after-glow. The detectors absorb the Xray photons and emit the energy as visible light. This is converted to electrons by a photomultiplier tube and then amplified. Analog outputs from these tubes go through signal conditioning circuitry that amplifies, clips and shapes the signals.

- A relatively simple analog-to-digital converter then prepares the signals for the computer. Simultaneously, a separate reference detector continuously measures the intensity of the primary X-ray beam .The set of readings thus produced enables the computer to compensate for fluctuations of X-ray intensity. Also, the reference readings taken at the end of each traverse are used to continually calibrate the detection system and the necessary correction is carried out.

- After the initial pre-processing, the final image is put onto the system disc. This allows for direct viewing on the operator’s console. The picture is reconstructed in either a 320 x 320 matrix of 0.73 mm squares giving higher spatial resolution or in a 160x 160 matrix of 1.5 mm, squares which results in higher precision, lower noise image and better discrimination between tissues of similar density.

- Each picture element that makes up the image matrix has a CT number. A complete picture occupies approximately 100 K words, and up to eight such pictures can be stored on the system disc. There is a precise linear relationship between the CT numbers and the actual X-ray absorption values, and the scale is defined by air at -1000 and by water at 0.

UNIT-V

DISPLAYS

Classification of displays - Display devices - Liquid Crystal Diode – Incandescent display - Liquid vapour display – Light Emitting Diode (LED)

5.1 Classification of displays

The development of medical imaging technologies has revolutionized healthcare, providing powerful diagnostic tools, supporting non-invasive assessment of injuries and internal issues, and enabling diseases to be detected far earlier than ever before.

Physicist Marie Curie helped develop X-rays—the first medical imaging technology—based on her Nobel-prize winning work with radioactive elements. Since then, MRI (magnetic resonance imaging), CT scans (computed tomography), ultrasound, nuclear medicine techniques such as positron emission tomography (PET), and other advanced imaging technologies have been added to the medical toolkit, offering different views into the human body. These non-invasive methods rely on different technologies to scan interior structures and produce images of bones, organs, and tissues to support diagnosis, medical monitoring, and treatment.

When they initially emerged, imaging technologies produced two-dimensional images on films, which had to be held up to a light source for reading. Subsequently, techniques were developed to combine multiple scans together into 3D renderings and to generate and capture both 2D and 3D images digitally for viewing on a computer screen.

Medical-Grade Displays

Display monitors used in medical settings need to offer enhanced performance and greater longevity (due to their constant usage) compared to the typical commercial and consumer displays. Medical displays usually come with special image-enhancing technologies to ensure constant brightness and clear and consistent images over the lifetime of the display. Some of the key considerations for medical displays include:

- **Resolution** – The higher the screen resolution, the greater the clarity and visible detail in an image—necessary for accurate diagnosis or research. The latest medical-grade display products offered by leading manufacturers include high-definition (HD), 4K, and up to 12-megapixel-resolution screens. The pixel pitch of typical devices is about 0.200 microns and the array sizes are 1536 x 2048 or larger.[1]
- **Luminance** – Luminance (often referred to as "brightness") is the amount of photon energy that reaches the eye, measured in units of candela (cd) per square meter (cd/m^2), also called "nits". The acceptable range for a radiology display, for example, is 350-420 nits.[2]
- **Contrast** – Also important is contrast, measured as the range of luminance available between the maximum luminance of a display pixel and when that pixel is "off".

Although in recent years manufacturers have been closing the gap with increased brightness, matrix sizes, decreased pixel pitch, and increased factory QA to ensure uniformity, consumer-grade displays haven't produced the same luminance and contrast as medical displays. Even if an LCD consumer-grade display starts out at 400 nits, after 18 months, its backlight performance will already have decayed to about 350 nits, effectively ending its lifespan for radiological use. To counter this, medical displays are designed with "headroom"—a maximum luminance capacity above that of its normal operating level, which can be tapped over time to compensate for the anticipated performance decay.

Many medical images (such as X-rays and mammograms) are monochromatic, so being able to discern fine luminance differences in grayscale is important. Medical imaging relies on the "just noticeable differences" (JND) standard first developed by NASA. JND is the smallest difference in luminance (e.g., between two gray levels) that the average observer can just perceive on the display system.

Calibration

To maintain stable peak luminance from cold start to full warm-up, and throughout its lifetime, a medical display has a closed-loop control circuit tied to a built-in photometer. The photometer monitors gamma levels and measures peak luminance several times a second, ensuring a consistent level of luminance. Monitors can also be periodically calibrated to ensure accuracy. By contrast, a commercial-grade (consumer) display simply offers a manual brightness control where a user can set their own preference, without reference to absolute luminance levels. Monochromatic medical-grade monitors have calibration features that meet the DICOM part 14 Grayscale Standard.

5.2 Incandescent display:

Incandescent alphanumeric displays using a 16-bar format are obtainable today. They employ 1-ml incandescent tungsten helices strung between support posts. This paper describes a new incandescent display device, fabricated by microelectronic thin-film techniques. Such techniques allow high-resolution dot-matrix displays to be produced with all the cost advantages obtained from the employment of modern LSI thin-film processing.

The device uses a ceramic substrate covered with a thick layer of glass. Holes are produced in the laminate and filled with metal to eventually form the element support posts. A thin layer of refractory metal is deposited on the glass.

The metal and glass are then etched to produce a field of free-standing microfilaments. The resulting display panel can be driven by simple integrated circuits, and the efficiency of the device, operating at 1200°C, is better than quoted for most light-emitting diodes (LED's).

5.3 Liquid Crystal Diode (LCD)

The LCD is defined as the diode that uses small cells and the ionised gases for the production of images. The LCD works on the modulating property of light.

The light modulation is the technique of sending and receiving the signal through the light. The liquid crystal consumes a small amount of energy because they are the reflector and the transmitter of light.

It is normally used for seven segmental displays.

Construction of LCD

The liquid crystals are the organic compound which is in liquid form and shows the property of optical crystals. The layer of liquid crystals is deposited on the inner surface of glass electrodes for the scattering of light. The liquid crystal cell is of two types; they are Transmittive Type and the Reflective Type.

Transmittive Type

In transmitter cell both the glass sheets are transparent so that the light is scattered in the forward direction when the cell becomes active.

Reflective Type

The reflective type cell consists the reflecting surface of the glass sheet on one end. The light incident on the front surface of the cell is scattered by the activated cell.

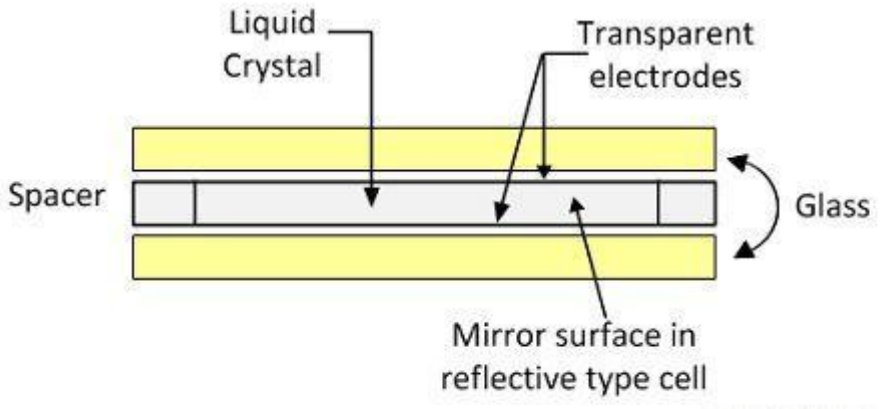


Figure 5.1 Liquid Crystal Diode (LCD)

Both the reflective and transmittive type cells appear brights, even under small ambient light conditions.

Working Principle of LCD

The working principle of the LCD is of two types. They are the dynamic scattering type and the field effects type. Their details explanation is shown below.

Dynamic Scattering

When the potential carrier flows through the light, the molecular alignment of the liquid crystal disrupts, and they produce disturbances. The liquid becomes transparent when they are not active. But when they are active their molecules turbulence causes scattered of light in all directions, and their cell appears bright. This type of scattering is known as the dynamic scattering. The construction of the dynamic scattering of the liquid crystal cell is shown in the Fig. 5.2

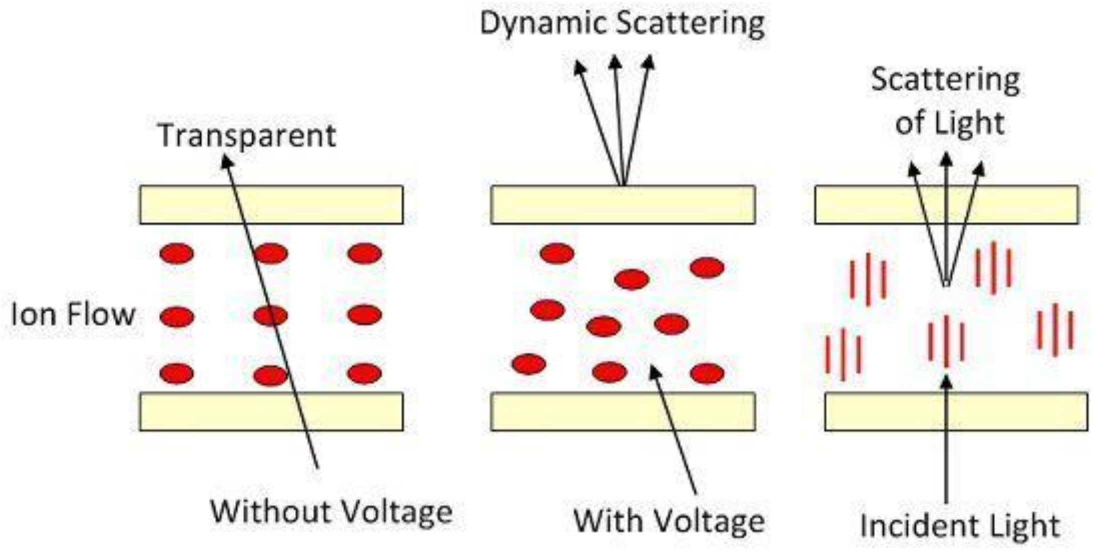


Figure 5.2 Dynamic Scattering

Field Effect Type

The construction of liquid crystals is similar to that of the dynamic scattering types the only difference is that in field effect type LCD the two thin polarizing optical fibres are placed inside the each glass sheet. The liquid crystals used in field effect LCDs are of different scattering types that operated in the dynamic scattering cell.

The field affects type LCD uses the nematic material which twisted the un energized light passing through the cell. The nematic type material means the liquid crystals in which the molecules are arranged in parallel but not in a well-defined plane. The light after passing through the nematic material passing through the optical filters and appears bright. When the cell has energised no twisting of light occurs, and the cell appears dull.

Advantages of LCD

The following are the advantages of LCD.

1. The power consumption of LCD is low. The seven segmental display of LCD requires about 140μW which is the major advantages over LED which uses approximately 40mW per numeral.
2. The cost of the LCD is low.

Disadvantages of LCD

The following are the disadvantages of LCD.

1. The LCD is a slow device because their turning on and off times are quite large. The turn-on time of the LCD is millisecond while there turn off time is ten milliseconds.
2. The LCD requires the large area.
3. The direct current reduces the lifespan of LCD. Therefore, the LCD uses with AC supply, having the frequency less than 500Hz.

The LCD requires AC voltage for working.

5.4 Liquid vapour displays:

Liquid vapour displays (LVDs) are the latest in economical display technology. They operate on the principle of a new reflective passive display and depend on the presence of ambient lights for their working. structure of a typical LVD cell is shown in Fig. 5.3

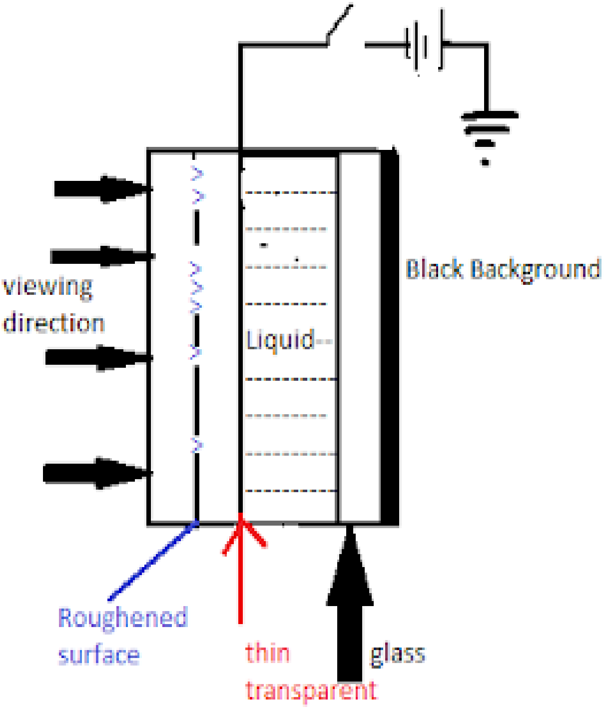


Figure 5.3 Liquid vapour displays (LVDs)

In its simplest form, It consists of roughened glass surface wetted with a transparent volatile of some refractive index as that of glass. The rear surface is blackened. A voltage drive is used for heating he transparent electrode.

In the "off" condition of display (i.e., with no voltage applied to the transparent electrode), the black background is seen through the front transparent glass electrode and the liquid. In "on" condition (i.e., with voltage applied to the transparent electrode), electrode gets heated causing the evaporation of liquid in contact with it, and, therefore, a combination of vapour film and vapour bubbles is formed around the roughened glass surface.

Since the refractive index of vapour is roughly unity here is a discontinuity established between the front glass plate and the liquid, which results in light scattering. This makes it a simple display device. This has a better contrast ratio as compared to LCD, but its speed of operation is low.

5.5 Light Emitting Diode

The working principle of an LED (Light Emitting Diode) is based on a phenomenon called electroluminescence, which is the emission of light from a material when an electric current is passed through it. LEDs are semiconductor devices that convert electrical energy directly into light without the need for heating a filament, as in incandescent bulbs. Here’s how an LED works:

1. **Semiconductor Material**: LEDs are made from semiconductor materials, typically gallium arsenide (GaAs), gallium phosphide (GaP), or gallium nitride (GaN). These materials have unique electronic properties that enable them to emit light when electrons recombine with holes.

2. **P-N Junction**: An LED consists of two different regions within the semiconductor material: the p-type region (positively charged) and the n-type region (negatively charged). The boundary between these two regions is called the p-n junction.

3. **Energy Band Diagram**: At the p-n junction, there is a potential energy barrier between the electrons in the n-region and the holes in the p-region. When a forward voltage (positive voltage at the anode and negative voltage at the cathode) is applied to the LED, the electrons from the n-region move toward the p-region, and the holes from the p-region move toward the n-region.

4. **Recombination**: As the electrons move across the p-n junction, they recombine with the holes. During this recombination process, the electrons lose energy, and this energy is released in the form of photons (light).

5. **Emission of Light**: The released photons have specific wavelengths depending on the energy bandgap of the semiconductor material. This determines the color of light emitted by the LED. For example, GaAs-based LEDs emit infrared light, while GaP-based LEDs emit visible light in various colors, and GaN-based LEDs emit blue or green light.

6. **Light Extraction**: The light generated within the semiconductor material needs to be extracted efficiently to produce useful illumination. The LED package is designed to maximize light extraction and direct the light output in the desired direction.

7. **Continuous Operation**: As long as a forward voltage is applied to the LED, the recombination process continues, and the LED emits light. LEDs can operate efficiently and emit light continuously for thousands of hours.

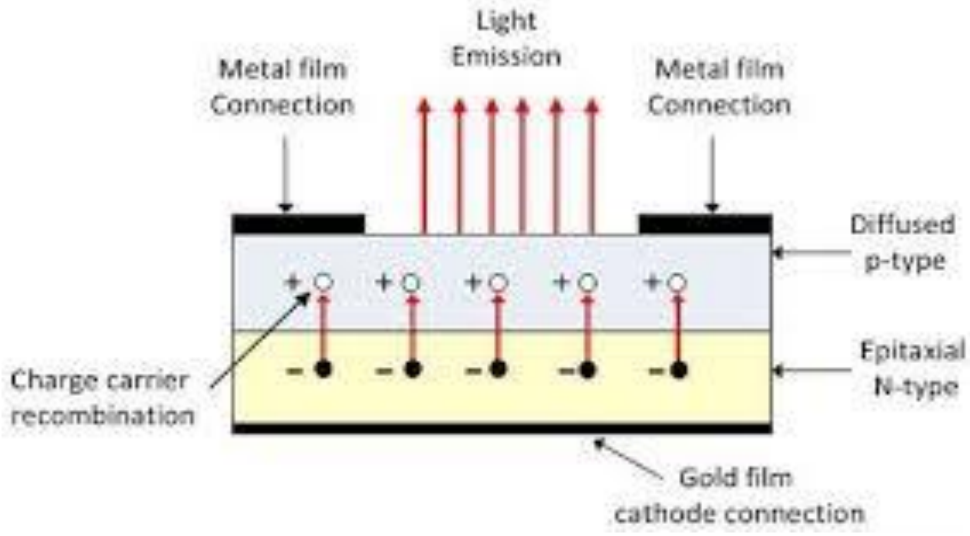


Figure 5.4 Light Emitting Diode

Overall, the working principle of an LED involves the controlled flow of electrons and holes across the p-n junction in a semiconductor material, leading to the emission of light. LEDs are known for their high energy efficiency, long operational life, and wide range of colors, making them a popular choice for various lighting applications.