BM T46 – BIOMEDICAL SENSOERS AND TRANSDUCERS

UNIT-1

2 MARKS

1. **Give the classification of transducers. (Sep 2020, May 2015)**

   On the basis of transduction form transducers are classified as follows
   - Primary and secondary type
   - Analog and digital type
   - Active and passive type
   - Transducer and Inverse type

2. **What are the errors in measurement? (Sep 2020)**
   - Systematic Errors.
   - Instrumental Errors:
   - Environmental Errors.
   - Observational Errors.
   - Random Errors.
   - Limiting Errors.
   - Gross Errors.

3. **What is parallax error? (May 2019)**

   Parallax error is an error of change in apparent position of the object that caused due to the way of looking at any measuring scale from different angles.

4. **How the standards of measurements are classified? (May 2019, Nov 2018, May 2018)**

   Standards of measurements are classified as:
   - International standards
   - Primary standards
   - Secondary standards
   - Working standards

5. **Differentiate between the static characteristics accuracy and precision. (Nov 2018, May 2018)**
   - Accuracy is how close a value is to its true value. An example is how close an arrow gets to the bull's-eye center.
   - Precision is how repeatable a measurement is. An example is how close a second arrow is to the first one (regardless of whether either is near the mark).

6. **Differentiate sensors and transducers with example. (Nov 2017)**

   A transducer is a device that is used to convert a non-electrical signal into an electrical signal whereas the sensor is used to measure the physical changes that occur in the surroundings like temperature, light, etc, and convert it into a readable signal.

   <u>Examples of sensors are:</u>
   - Barometer
   - Accelerometer

   <u>Examples of transducers are:</u>
   - Thermocouple
   - Microphones

7. **What is primary standard? (Nov 2017)**
   - A primary standard in metrology is a standard that is sufficiently accurate such that it is not calibrated by or subordinate to other standards. Primary standards are defined via other quantities like length, mass and time.
   - Primary standards are used to calibrate other standards referred to as working standards.

8. **List out the difference between random and systemic errors with example. (May 2017, Nov 2015)**

   <u>Random Errors</u>:

   Random errors in experimental measurements are caused by unknown and unpredictable changes in the experiment.

   <u>Examples of causes of random errors are:</u>

   1. Electronic noise in the circuit of an electrical instrument,

   2. Irregular changes in the heat loss rate from a solar collector due to changes in the wind.

Systematic Errors:

Systematic errors in experimental observations usually come from the measuring instruments.

Examples of systematic errors are:

Errors in measurements of temperature due to poor thermal contact between the thermometer and the substance whose temperature is to be found.

9. What are the static characteristics of measurement system? (May 2017, May 2015)

- Accuracy
- Sensitivity
- Repeatability
- Reproducibility

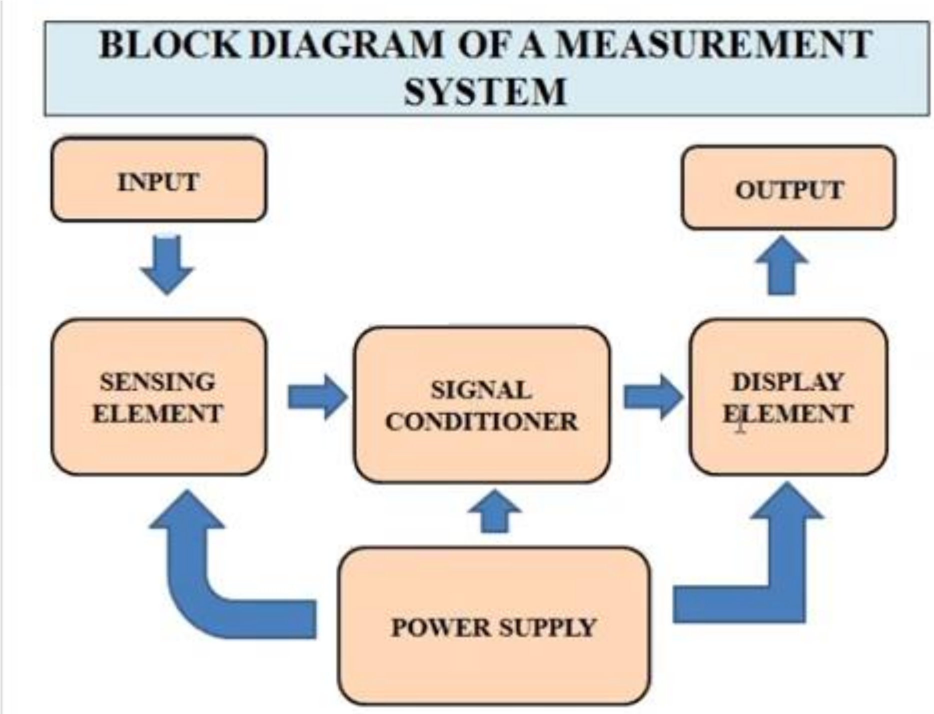
10. Give two examples of primary measurement. (Nov 2016)

- In primary mode, the sought value of a physical parameter is determined by comparing it directly with reference standards. The requisite information is obtainable through senses of sight and touch.
- Examples are matching of two lengths when determining the length of an object with a ruler.

11. Define calibration. (Nov 2016, May 2016)

- Calibration is the activity of checking, by comparison with a standard, the accuracy of a measuring instrument of any type.
- It may also include adjustment of the instrument to bring it into alignment with the standard.

12. Draw and explain the block diagram of the measurement system. (May 2016, Nov 2015)



<u>11 MARKS</u>

1. **Classify transducers. Explain the characteristics of transducer in details. (Sep 2020, Nov 2015)**

<u>Transducers:</u>

- An electrical or electronic device that follows the principle of transduction is known as transducers.
- These devices are installed at the boundaries of automation and control systems.
- The prominent factor to be considered in transducers is their efficiency.
- No transducer is cent percent efficient.

<u>Transducer Types:</u>

- The basic classification of the transducer is mechanical and electrical transducers.
- The transducers which respond to the minute changes in the environment are known as mechanical transducers.
- The change in the physical signal to the electrical form is referred to as electrical transducers.
- Transducers are classified based on various criteria. For example Temperature, Pressure, Displacement are the quantities. To measure these quantities there are specific transducers.

- Further, the operation involved categorizes the transducers are Piezoelectric, hall effect, photoconductors, etc…
- The condition of the supply provided makes the transducers to categorize into two types known as Active and Passive transducers.
- The active type of transducers doesn't require any sort of supply.
- The working of it is dependent upon the principle of conversion of energy involved in it.
- The transducer which requires external supply so that the operation of conversion takes place is known as Passive Transducers.
- The output signal generated is consists of a sort of electrical parameters. Some of the most commonly used types of transducers are listed as follows:

Piezoelectric Transducers

- A transducer that utilizes the piezoelectric effect to measure the change in the quantity of temperature, pressure or acceleration, etc… by the conversion of energy in terms of electric form. This type of transducer is known as a piezoelectric transducer.

Pressure Transducers

- Pressure transducers are also referred to as pressure transmitters. The transducer generates the outputs as an electrical signal when the pressure is exerted as input is known as a pressure transducer.
- It consists of two essential parts. The elastic material gets deformed when the pressure gets exerted followed by an electrical device to detect the deformation.

Temperature Transducers

- It is a type of transducer that converts the physical quantity that is temperature into electrical quantity. The thermocouple is the best example of the temperature transducer.
- It generates the electrical signals based on the difference in temperature among the terminals.

Ultrasonic Transducers

- The transducers that are capable of converting the ultrasonic waves in the form of electrical signals are known as ultrasonic transducers.

Transducer Characteristics

The characteristics of transducers are classified into two types static and dynamic.

The static characteristics of the transducers are:

- Accuracy - The output generated is proportional to the quantity that should be measured. Hence linearity is one of the characteristics of transducers. A transducer must be rugged enough to withstand the condition of overloading.
- Repeatability
- Highly stable
- Reliability
- Sensitivity
- Minimal size

The transducers whose changes in the output are the functions of time possess dynamic characteristics.

The dynamic characteristics based on which the transducers are selected are:

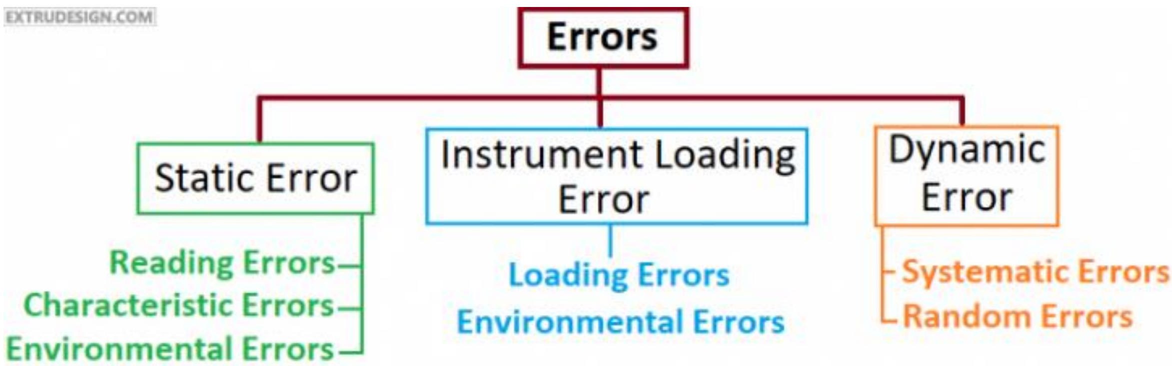
- Error (occurred dynamically)
- Dynamic Range
- Fidelity
- Speed of output obtained

Both the static and dynamic characteristics determine the overall performance of the transducers. The selection criteria for these devices are based on such parameters.

2. **What are the sources of errors? Discuss in detail the primary and secondary standards.(Sep 2020, Nov 2016)**

<u>Sources of Errors:</u>

Sources of errors in measurement are nothing but the different error possibilities in the measurement. the different types of errors are listed as a tree diagram below.



<u>Static Errors:</u>

There are three static errors those are Reading errors, Characteristic errors, Environmental errors. The static error means no relation to the time variation in the measurement, only related to the physical nature of the measuring instrument. That is what a static Error means.

i) Reading error: Reading errors such as reading with parallax error: Observing the readings from the dial without putting it normal to the eye.

ii.) Interpolation error: Taking correct interpolation when the indicator is in between two graduations.

iii) Characteristic Error:

Not able to attain the theoretical performance of the Instrument in taking an actual measurement.

iv) Environmental Errors:

Environmental factors such as wind, surrounding temperature, humidity, effects the on measuring instruments.

- Even the electrical and the magnetic field also influence the error in the measuring instruments while in static measurement.
- This environmental error is also a source of an error under instrumental loading errors.

Instrumental Loading Errors:

- Instrument loading errors mean, due to the measuring instrument the object which needs to be measured tends to change.
- For example, due to applying overpressure on the object by using the measuring instrument forcibly, the object may tend to change its shape and gives us an error.
- The environmental factor also affects the object to change in its parameter and becomes a source of an error as we said earlier.

Dynamic Errors:

- Dynamic errors mean the error caused by the time variation in the measurand(the object being measured).
- The main factor causes the dynamic error are the inertia, damping, friction in the sensing system or the display system of the measuring instrument.
- There are two different dynamic errors. They are

i) Systematic Errors:

- These systematic errors areRegular or repeats in nature and also can be controllable. (Repeats after a certain amount of time) can be eliminated sometimes.
- Calibration errors, variation in the contact pressure, variation in the atmospheric pressure, Parallax error, misalignment errors are the sources of Systematic errors.

ii) Random Errors:

- These Random Errors areErrors randomly occurred with the measuring instrument. (Unable to predict the when the error going to happen)Hard to control.
- Can be corrected in the final results.
- Error due to the variation of in the setting of the workpiece and the instrument, Due backlash and friction in the components of the measuring instruments are the sources of the Random errors in measurement.

STANDARDS:

- The standards of measurements are very useful for calibration of measuring instruments.
- They help in minimizing the error in the measurement systems. On the basis of the accuracy of measurement the standards can be classified as primary standards and secondary standards.

Primary Standard:

- A primary standard quantity will have only one value and it is fixed. An instrument which is used to measure the value of primary standard quantity is called primary standard instrument.
- It gives the accurate value of the quantity being measured.
- No precalibration is required for this instrument.
- It is used to calibrate the instruments having less accuracy.
- By comparing the readings of the two instruments, the accuracy of the second instrument can be determined.

Secondary Standard:

- The value of the secondary standard quantity is less accurate than primary standard one.
- It is obtained by comparing with primary standard. For measurement of a quantity using secondary standard instrument, pre-calibration is required.
- Without calibration, the result given by this instrument is meaningless.

- Calibration of a secondary standard is made by comparing the results with a primary standard instrument or with an instrument having high accuracy or with a known input source.
- In practical fields, secondary standard instruments and devices are widely used.
- Using calibration charts, the error in the measurement of these devices can be reduced.

3. Elaborate on the various Static and dynamic characteristics of a measurement system. (May 2019, Nov 2018, May 2018, May 2017, May 2016, May 2015)

The performance characteristics of electrical measuring instruments can be divided into two categories:

- Static characteristics
- Dynamic characteristics

STATIC CHARACTERISTICS:

Some applications involve the measurement of quantities that are either constant or vary slowly with time. Under these circumstances, it is possible to define a set of criteria that gives a meaningful description of the quality of measurement without interfering with dynamic descriptions that involve the use of differential equations. These criteria are called static characteristics.

The main static characteristics are

1. Accuracy:

It is the closeness with which an instrument reading approaches the true value of the quantity being measured. Thus accuracy of a measurement means conformity to truth. It the important static characteristic of electrical measuring instruments. Accuracy can be specified in terms of inaccuracy or limits of errors and can be expressed in the following ways:

a. Point accuracy:

This is the accuracy of the instrument only at one point on its scale.The specification of this accuracy does not give any information about the accuracy at other points on the scale or in the words, does not give any information about the general accuracy of the instrument.

b. Accuracy as percentage of scale range:

When an instrument has uniform scale, it's accuracy may be expressed in terms of scale range.

c. Accuracy as percentage of true value:

The best way to conceive the idea of accuracy is to specify it in terms of the true value of the quantity being measured within +0.5% or -0.5% of true value.

2. Precision:

- It is a measure of the reproducibility of the measurements i.e., given a fixed value of quantity, precision is a measure of the degree of agreement within a group of measurements.
- The term precise means clearly or sharply defined.As an example of the difference in meaning of the two terms accuracy and precision, suppose that we have an ammeter which possesses high degree of precision by virtue of its clearly legible, finely divided, distinct scale and a knife edge pointer with mirror arrangements to remove parallax.
- It is also theimportant static characteristic of electrical measuring instruments.

3. Stability:

- The ability of a measuring system to maintain standard of performance over prolonged periods of time
- Zero stability defines the ability of an instrument restore to zero reading after the input quantity has been brought to zero, while other conditions remain the same.

4. Resolution:

- If the input to an instrument increases slowly from some arbitrary non-zero value, it will be observed that the output of the instrument does not change at all until there is a certain minimum increment in the input.
- This minimum increment in what is input is called resolution of the instrument.
- Thus, the resolution is defined as the smallest incremental of the input quantity to which the measuring system responds.
- This is the third most important static characteristic of electrical measuring instruments.

- Resolving power or discrimination power is defined as the ability of the system to respond to small changes of the input quantity.
- One of the major factors influencing the resolution of an instrument is how finely its output scale is subdivided.
- If the input to an instrument is increased very gradually from zero value, there will be some minimum value of input below which no output change can be observed or detected.
- This minimum value of input defines the threshold of the instrument.

5. Threshold:

- If the instrument input is increased very gradually from zero there will be some minimum value below which no output change can be detected.
- This minimum value defines the threshold of the instrument. In specifying threshold, the first detectable output change is often described as beingany noticeable measurable change.

6. Drift:

- It is a slow variation in the output signal of a transducer or measuring system which is not due to any change in the input quantity.
- It is primarily due to changes in operating conditions of the components inside the measuring system.
- The drift is noticeable as zero drift and sensitivity drift.
- Zero drift is a deviation observed in the instrument output with time from the initial value, all the other measurement conditions are constant.
- This may be caused by a change in component values due to variation in ambient conditions or due to ageing. Typical units by which zero drift is measured are volts per °C in the case of a voltmeter affected by changes in ambient temperature.
- This is often called the zero drift coefficient related to temperature changes.

7. Repeatability:

- It is the characteristic of precision electrical measuring instruments.
- It describes the closeness of output readings when the same input is applied repetitively over a short period of time, with the same measurement conditions, same

instrument and observer, same location and same conditions of use maintained throughout.

- It is affected by internal noise and drift.
- It is expressed in percentage of the true value.
- Measuring transducers are in continuous use in process control operations and the repeatability of the performance of the transducer is more important than the accuracy of the transducer, from considerations of consistency in product quality.

8. Reproducibility:

- It is the closeness with which the same value of the input quantity is measured at different times and under different conditions of usage of the instrument and by different instruments.
- The output signals and indications are checked for consistency over prolonged periods and at different locations.
- Perfect reproducibility ensures interchangeability of instruments and transducers.

9. Dead Zone:

- It is the largest change of input quantity for which there is no output of the instrument.
- For instance, the input applied to the instrument may not be sufficient to overcome the friction and will, in that case not move at all.
- It is due to either static friction (stiction), backlash or hysteresis.
- Dead zone is also known as dead band dead Space. All elastic mechanical elements used as primary transducers exhibit effects of hysteresis, creep and elastic after- effect to some extent.

10. Backlash:

- The maximum distance or angle through which any part of the mechanical system may be moved in one direction without applying appreciable force or motion to the next part in a mechanical sequence.

11. Hysteresis:

- Hysteresis is a phenomenon which depicts different output effects when loading and unloading whether it is a mechanical system or any electrical system or any other system.

- Hysteresis is the difference in the readings of an instrument, which fixed value of the input signal, which depends on whether that input value is approached from increasing or decreasing values of input.
- That is upscale and down scale deflections do not coincide when the measurement is made of the same value by the method of symmetry.
- The non-coincidence between the loading and unloading curves is known as hysteresis.

12. Linearity:

- It defines the proportionality between input quantity and output signal.
- If the sensitivity is constant for all values from zero to full scale value of the measuring system, then the calibration characteristic is linear and is a straight line passing through the origin.
- If it is an indicating or recording instrument the scale may be made linear.
- In case there is a zero error the characteristic assumes the form of the equation given by $y = mx + c$ where y is output, x is input, m is slope and c is intercept.
- Linearity is the closeness of the calibration curve of a measuring system to a straight line.
- If an instruments calibration curve for desired input is not a straight line, the instrument may still be highly accurate. In many applications, however, linear response is most desirable.

13. Range or Span:

- Span and range are the two terms that convey the information about the lower and upper calibration points.
- The range of indicating instruments is normally from zero to full scale value and the Span is simply the difference between the full scale and lower scale value.
- But same instruments operate under a bias so that they start reading, for example, voltages from 5V to 25V only. The zero of these instruments is suppressed from indication by means of a bias.
- In such case, the scale range is said to be from 5V to 25V and the scale span is 25-5 i.e., 20V.

14. Bias:

- Bias describes a constant error which exits over the full range of measurement of an instrument.
- The error is normally removable by calibration.

15. Tolerance:

- It is a term which is closely related to accuracy and defines the maximum error which is to be expected in some value.
- While it is not, strictly speaking, a static characteristic of measuring instruments, it is mentioned here because the accuracy of some instruments, is sometimes quoted as a tolerance figure.
- Tolerance, when used correctly, describe the maximum deviation of a manufactured component from some specified value.
- Electric circuit components such as resistors have tolerances of perhaps 5%.

DYNAMIC CHARACTERISTICS:

Measurement systems having inputs dynamic in nature, the input varies from instant to instant, so does the output. The behavior of the system under such conditions is dealt by the dynamic response of the system and its dynamic characteristics of electrical measuring instruments are given below:

1. Dynamic error:

- It is the difference of true value of the quantity changing with the time the value indicated by the instrument provided static error is zero.
- Total dynamic error is the phase difference between input and output of the measurement system.

2. Fidelity:

- It is the ability of the system to reproduce the output in the same form as the input.
- In the definition of fidelity any time lag or phase difference is not included.
- Ideally a system should have 100% fidelity and the output should appear in the same form as the input and there is no distortion produced by the system.
- Fidelity needs are different for different applications.

3. Bandwidth:

- It is the range of frequencies for which its dynamic sensitivity is satisfactory.
- For measuring systems, the dynamic sensitivity is required to be within 2% of its statics sensitivity.
- For other physical systems, electrical filters electronic amplifiers, the above criterion is relaxed with the result that their bandwidth specification extend to frequencies at which the dynamic sensitivity is 70.7 % of that at zero or the mid- frequency.

4. Speed of response:

- It refers to its ability to respond to sudden changes of amplitude of input signal.
- It is usually specified as the time taken by the system to come close to steady state conditions, for a step input function.
- Hence the speed of response is evaluated from the knowledge of the system performance under transient conditions and terms such as time constant, measurement lag, settling time and dead time dynamic range are used to convey the response of the variety of systems, encountered in practice.
- This is the important dynamic characteristics of electrical measuring instruments.

5. Time constant:

- It is associated with the behaviour of a first order system and is defined as the time taken by the system to reach 0.632 times its final output signal amplitude.
- System having small time constant attains its final output amplitude earlier than the one with larger time constant and therefore, has higher speed of response.

6. Measurement lag:

- It is defined as the delay in the response of an instrument to a change in the measurand.
- This lag is usually quite small but it becomes quite significant where high-speed measurements are required.
- Measurement lag is of two types.
  - In retardation type, the response of the instrument begins immediately after a change in the measurand has occurred.

- ➢ In time delay type, the response of the system begins after a delay time after application of the input.

7. Settling time:

- ❖ It is the time required by the instrument or measurement system to settle down to its final steady state position after the application of the input.
- ❖ For portable instruments, it is the time taken by the pointer to come to rest within -0.3% to +0.3% of its final scale length while for panel type instruments, it is the time taken by the pointer to come to rest within -1% to +1% of its final scale length.
- ❖ Smaller settling time indicates the highest speed of response.
- ❖ Settling time is also dependent on the system parameters and varies with the conditions under which the system operates.
- ❖ This is also the important dynamic characteristics of electrical measuring instruments.

4. Explain direct and indirect comparison calibration methodology. (Nov 2018, May 2018)

Direct method of measurement:

- ❖ In this method the value of a quantity is obtained directly by comparing the unknown with the standard.
- ❖ It involves no mathematical calculations to arrive at the results, for example, measurement of length by a graduated scale.
- ❖ The method is not very accurate because it depends on human insensitiveness in making judgement.
- ❖ Parameter estimation is extremely relevant for accurate simulation of groundwater flow.
- ❖ Parameter values for models of large-scale catchments are usually derived from a limited set of field observations, which can rarely be obtained in a straightforward way from field tests or laboratory measurements on samples, due to a number of factors, including measurement errors and inadequate sampling density.
- ❖ Indeed, a wide gap exists between the local scale, at which most of the observations are taken, and the regional or basin scale, at which the planning and management decisions are usually made.

- The use of geologic information and field data is generally made by zoning the parameter fields.
- In fact, the support of the hydraulic conductivity measured in the field is normally much smaller than the cell size of the numerical model, so it should be up scaled to a scale consistent with that of the numerical model discretization.
- Automatic inverse calibration is a valuable procedure to identify model parameter values by conditioning on observed, available data, limiting the subjective evaluations introduced with the trial-and-error technique.
- Direct methods allow determination of hydraulic conductivities from the groundwater flow equations which relate the conductivity and head fields.
- Both approaches has pros and cons, depending also on model complexity.
- Direct measurement is performed using the scale of the measuring instrument.
- In a direct comparison, a source or generator applies a known input to the meter under test.
- The ratio of what meter is indicating and the known generator values gives the meter's error.
- In such case the meter is the test instrument while the generator is the standard instrument.
- The deviation of meter from the standard value is compared with the allowable performance limit.
- With the help of direct comparison a generator or source also can be calibrated.

Indirect method of measurement:

- In this method several parameters are measured directly and then the value is determined by mathematical relationship.
- For example, measurement of density by measuring mass and geometrical dimensions.
- In an indirect calibration, the value of the standard is expressed in a quantity different from the output one, that is, the measurement and the measurand are different.
- This is the most common kind of calibration in chemical analysis, for example, the calibration of a spectrophotometric method.
- Indirect measurement is a method of using proportions to find an unknown length or distance in similar figures.
- Two common ways to achieve indirect measurement involve

- Using a mirror on the ground and
- Using shadow lengths and find an object's height.

- The dimensions are measured using measuring instruments such as dial gauges that look at the difference between targets and reference devices such as gauge blocks and ring gauges.
- In the indirect comparison, the test instrument is compared with the response standard instrument of same type.
- If the test instrument is a meter then the same input is applied to the test meter as well a standard meter.
- In case of generator calibration, the output of the generator tester as well as standard, or set to same nominal levels.
- Then the transfer meter is used which measures the outputs of both standard and test generator.

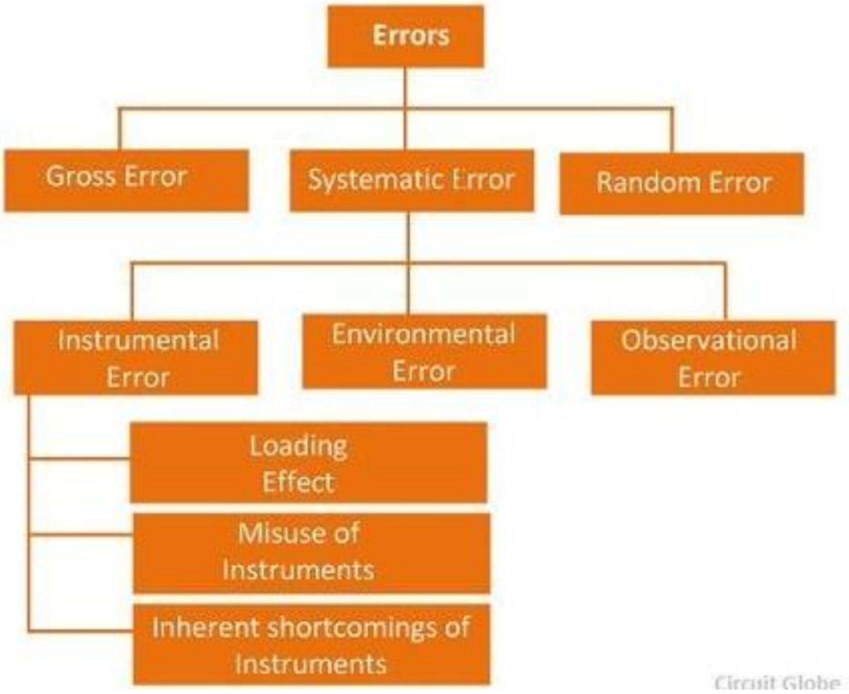
5. Explain the errors in measurements by giving suitable examples. (May 2019, Nov 2017, Nov 2016, May 2016)

The measurement error is defined as the difference between the true or actual value and the measured value. The true value is the average of the infinite number of measurements, and the measured value is the precise value.

<u>Types of Errors in Measurement</u>

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



1. Gross Errors:

- The gross error occurs because of the human mistakes.
- For examples consider the person using the instruments takes the wrong reading, or they can record the incorrect data.
- Such type of error comes under the gross error. The gross error can only be avoided by taking the reading carefully.
- For example – The experimenter reads the 31.5ºC reading while the actual reading is 21.5Cº.
- This happens because of the oversights. The experimenter takes the wrong reading and because of which the error occurs in the measurement.
- Such type of error is very common in the measurement. The complete elimination of such type of error is not possible. Some of the gross errors easily detected by the experimenter but some of them are difficult to find.
- Two methods can remove the gross error. These methods are
    - The reading should be taken very carefully.
    - Two or more readings should be taken of the measurement quantity. The readings are taken by the different experimenter and at a different point for removing the error.

2. Systematic Errors:

The systematic errors are mainly classified into three categories.

- Instrumental Errors
- Environmental Errors
- Observational Errors

(i) Instrumental Errors

These errors mainly arise due to the three main reasons.

(a) Inherent Shortcomings of Instruments

- ❖ Such types of errors are inbuilt in instruments because of their mechanical structure.
- ❖ They may be due to manufacturing, calibration or operation of the device.
- ❖ These errors may cause the error to read too low or too high.
- ❖ For example – If the instrument uses the weak spring then it gives the high value of measuring quantity. The error occurs in the instrument because of the friction or hysteresis loss.

(b) Misuse of Instrument

- ❖ The error occurs in the instrument because of the fault of the operator.
- ❖ A good instrument used in an unintelligent way may give an enormous result.
- ❖ For example – the misuse of the instrument may cause the failure to adjust the zero of instruments, poor initial adjustment, using lead to too high resistance. These improper practices may not cause permanent damage to the instrument, but all the same, they cause errors.

(c) Loading Effect

- ❖ It is the most common type of error which is caused by the instrument in 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.

(ii) Environmental Errors

- These errors are due to the external condition of the measuring devices.
- Such types of errors mainly occur due to the effect of temperature, pressure, humidity, dust, vibration or because of the magnetic or electrostatic field.
- The corrective measures employed to eliminate or to reduce these undesirable effects are
- The arrangement should be made to keep the conditions as constant as possible.
- Using the equipment which is free from these effects.
- By using the techniques which eliminate the effect of these disturbances.
- By applying the computed corrections.

(iii) Observational Errors

- Such types of errors are due to the wrong observation of the reading. There are many sources of observational error.
- For example, the pointer of a voltmeter resets slightly above the surface of the scale.
- Thus an error occurs (because of parallax) unless the line of vision of the observer is exactly above the pointer.
- To minimise the parallax error highly accurate meters are provided with mirrored scales.

3. Random Errors:

- The error which is caused by the sudden change in the atmospheric condition, such type of error is called random error.
- These types of error remain even after the removal of the systematic error. Hence such type of error is also called residual error.

6. With a neat block diagram, explain the basic instrumentation system with examples for each block. (Nov 2017)

- The measurement and control of physical conditions is very important in many industrial and consumer applications.
- For example, the operator may make necessary adjustments in the measurement of temperature or humidity inside a dairy or meat plant to maintain the product quality, or to produce a particular type of plastic, precise temperature control of the plastic furnace is needed.
- A transducer is generally used at the measuring site to obtain the required information easily and safely.
- A transducer is a device that converts one form of energy into another.
- For example, when a strain gauge is subjected to pressure or force (physical energy), the resistance of the strain gauge changes (electrical energy), i.e. it converts mechanical energy into electrical energy.
- Actually, an instrumentation system is used to measure the output signal produced by the transducer and mostly used to control the physical condition producing the output signal.

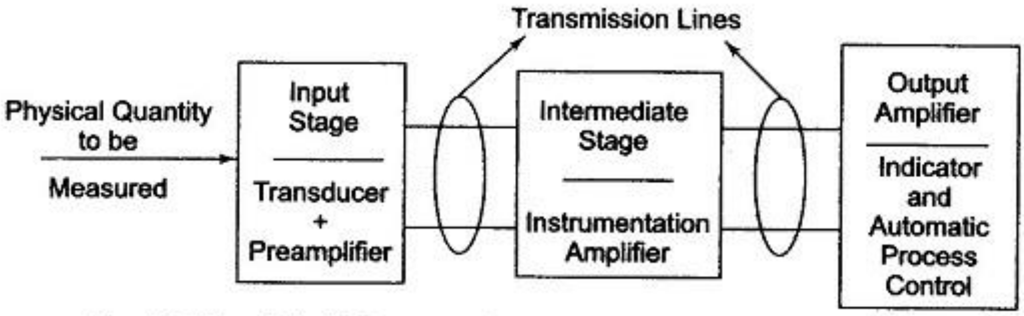


Fig. 14.24 Block Diagram of an Instrumentation System

- The simplified form of such an instrumentation system is shown in above fig.This instrumentation system consists of a type of transducer as the input stage, depending upon the physical quantity to be measured.
- The transducers output is fed to the pre-amplifier. The instrumentation amplifier is the intermediate stage.

❖ The output of the instrumentation amplifier can be connected to various devices, such as meter, oscilloscope, charts or magnetic recorders.

❖ Advanced technology has led to use of automatic instrumentation systems. These systems have an automatic process controller used at the output stage, which compensates for changes in the operating condition.

❖ The lines connecting the various stages, as shown in above figure are called the transmission lines.

❖ On the system requirement and the physical quantity to be monitored, the length of these transmission lines are chosen. These transmission lines permit signal transfer from unit to unit.

7. Explain with neat diagram (May 2017, May 2015)

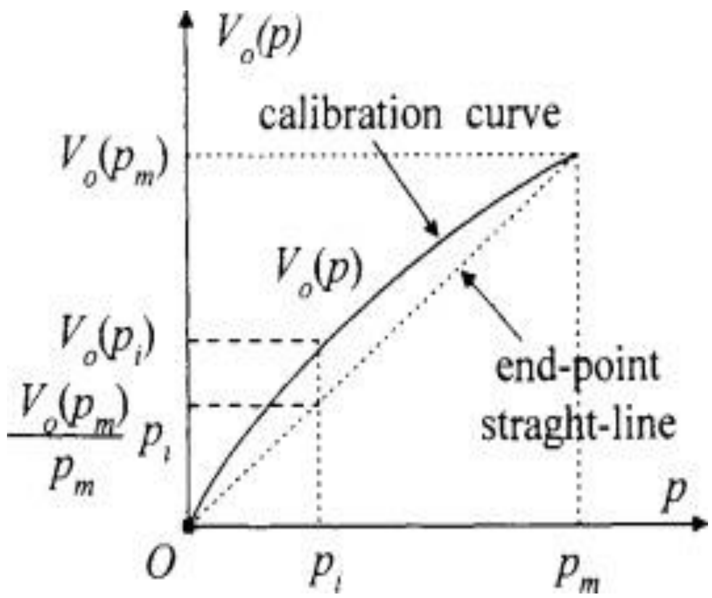
(a) Error calibration curve

(b) Types of drift

a.) <u>ERROR CALIBRATION CURVE:</u>

❖ Calibration curves are used to understand the instrumental response to an analyte, and to predict the concentration of analyze in a sample.

❖ A calibration curve is created by first preparing a set of standard solutions with known concentrations of the analyses.



- A calibration curve, also non as a standard curve, is a general method for determining the concentration of a substance in an unknown sample by comparing the unknown to a set of standard samples of known concentration.
- A calibration curve is one approach to the problem of instrument calibration; other standard approaches may mix the standard into the unknown, giving an internal standard.
- The calibration curve is a plot of how the instrumental response, the so-called analytical signal, changes with the concentration of the analyte (the substance to be measured).
- The operator prepares a series of standards across a range of concentrations near the expected concentration of analyte in the unknown.
- The concentrations of the standards must lie within the working range of the technique (instrumentation) they are using.
- Analyzing each of these standards using the chosen technique will produce a series of measurements.
- Calibration curve is a regression model used to predict the unknown concentrations of analytes of interest based on the response of the instrument to the known standards.
- Some statistical analyses are required to choose the best model fitting to the experimental data and also evaluate the linearity and homoscedasticity of the calibration curve.
- Using an internal standard corrects for the loss of analyze during sample preparation and analysis provided that it is selected appropriately.
- After the best regression model is selected, the analytical method needs to be validated using quality control (QC) samples prepared and stored in the same temperature as intended for the study samples.
- Most of the international guidelines require that the parameters, including linearity, specificity, selectivity, accuracy, precision, lower limit of quantification (LLOQ), matrix effect and stability, be assessed during validation.

b.) TYPES OF DRIFT:

There are three types of drift

- Zero drift
- Span drift

➢ Zonal drift

Zero drift

❖ Zero drift or bias describes the temperature effect where the zero reading of an instrument is modified by a change in ambient conditions.

❖ This causes a constant error that exists over the full range of measurement of the instrument.

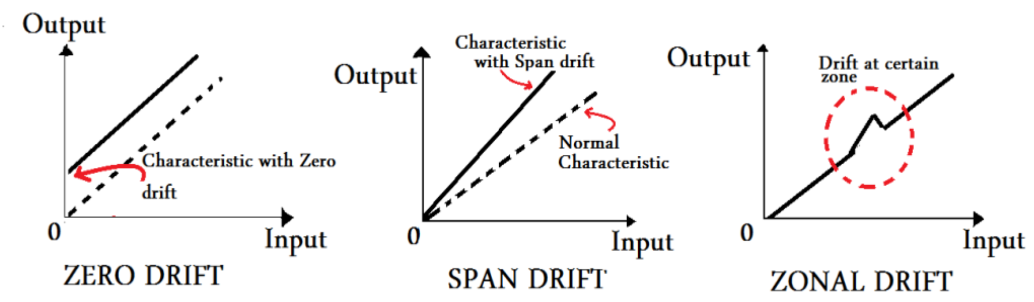
❖ It is defined as the gradual change in the scale zero of a measuring instrument (as a thermometer or a galvanometer).

❖ All sensors are affected by environmental conditions and use over time.

❖ The output at zero reading will drift slightly over time.

❖ Some types of sensors will exhibit a greater amount of zero drift at the beginning due to settling-in period of the materials used in the construction of the sensor.

❖ Other sensors may get worse over time because the sensor performance characteristic has deteriorated due to heavier temperature than normal use over the typical service life of the sensor.



Span drift (or) Sensitivity drift:

❖ If there is proportional change in the indication all along the upward scale, the drift is called span drift or sensitivity drift.

❖ Sensitivity drift (also known as scale factor drift) defines the amount by which an instrument's sensitivity of measurement varies as ambient conditions change.

❖ Sensitivity drift (also known as scale factor drift) defines the amount by which an instrument's sensitivity of measurement varies as ambient conditions change.

❖ It is quantified by sensitivity drift coefficients that define how much drift there is for a unit change in each environmental parameter that the instrument characteristics are sensitive to.

- Many components within an instrument are affected by environmental fluctuations, such as temperature changes: for instance, the modulus of elasticity of a spring is temperature dependent.
- what effect sensitivity drift can have on the output characteristic of an instrument. Sensitivity drift is measured in units of the form (angular degree/bar)/°C.
- Sensitivity drift causes loss of transducer sensitivity, because for the same input variation, the transducer responds with smaller variation than expected.
- It is usually due to changes in ambient conditions, as temperature and atmospheric pressure, and due to instability of the electronic circuit's power supply, which changes the voltage gain of biopotential amplifier

Zonal drift:

- Repeatability is the degree of agreement between results of successive measurements of the same variable carried out under the same measurement conditions (same operator, same transducer).
- Repeatability of a transducer can vary along time, which does not necessarily indicate it is faulty, but rather that repeatability is a variable quantity.
- Reproducibility is the degree of agreement between results of successive measurements of the same variable carried out under different measurement conditions (same operator but different transducers or same transducer but different operators).
- When the drift occurs only over a portion of the full scale or span of an instrument, it is called zonal drift.
- Drift is an undesirable quantity that is rarely apparent and is hard to compensate for.
- Thus, it needs to be carefully guarded against by continuous prevention, inspection and maintenance.

8. Explain how the Transducers are derived. (Nov 2015)

A transducer is a device which converts a non-electrical quantity into an electrical quantity. It comprises of a detecting sensing element and a transduction element.

Types of transducer

- On the basis of transduction element
  - Capacitive,
  - Inductive and

- Resistive transducer.

- Primary and secondary transducer
- Active and passive transducer
- Analog and digital transducer
- Inverse transducer

Primary and secondary transducer:

- It is the detecting or sensing element which responds to the change in physical phenomena.
- Whereas the secondary transducer converts the output of primary transducer into electrical output.
- Example: For the compressive force with the help of load cell and strain gauge
- Load cell is a short column or a strut with resistance wire strain gauge bonded to it.
- We measure of applied on the load cell, a strain is produced in it. The force is force is first detected by the column and is converted into the strain which is basically a mechanical displacement.
- The higher the applied force the more will ne strain generated in the column.
- This stain changes the resistance of strain gauge.
- Thus we have output in the form of change in resistance of strain gauge is calibrated with the applied force and hence output of the strain gauge directly indicates the value of applied force.
- That force is detected by the column in the first stage and hence it is called the primary transducer.
- The output signal from the primary transducer is converted subsequently into an electrical output bythe strain gauge and therefore they are known as secondary transducer.

Passive and active transducer:

Passive transducer:

- A transducer which requires external power supply to function is called passive transducer.
- This external power supply is called auxillary power supply and required for the functioning of transduction element.

- This type of transducer is also called externally powered transducer.
- POT is an example of passive transducer. It is used to covert a linear displacementinto electrical signal.
- POT is basically a resistance wire which is connected to an external power source ei.
- The linear displacement is xi and the output voltage is e0.
- Let the length of resistance wire be L and total resistance be Rt. When linear displacement is Xi, the resistance of wire across the e0 is (Rt/L)Xi and hence the output voltage e0 will be given by voltage division rule.

$$E0 = [ei\ (Rt / L)\ Xi] / Rt$$

$$=ei\ (Xi/L)$$

$$Xi = (e0/ei)L$$

- From above, example it is clear that the linear displacement is directly proportional to the output voltage for a given input voltage for a given input voltage and resistance length.
- It can also be observed that a POT cannot work if external power supply is not connected.

Active transducer:

- Active transducers are those which does not require external power supply to work.
- This doesn't mean that these types of transducers don't require power at all.
- In fact, the power required for functioning is derived from the physical change itself.
- Example for active transducer: piezoelectric crystal.
- It should be noted that no external source of power is required to work for an accelerometer. Hence it is an active transducer.

Analog and digital transducer:

Analog Transducer:

- Analog transducers are those whose output is continuous in time domain.
- This essentially means that the electrical output signal will be continuous function of time.
- Example: RTD, Thermocouple, LVDT, RVDT, Thermistor etc.

- In RTD and Thermocouple the output signal is inn the form of voltage which is always available.

Digital transducer:

- Transducer which convert the input quantity into an electrical output signal which is in the form of pulse is called digital transducer.
- The output is not continuous rather it is in the form of pulse which means that it is discrete.
- Example: shaft encoder, limit switch, digital tachometer,

<u>Inverse transducer:</u>

Transducer:

- Devices which convert a non- electrical quantity into an electrical quantity is popularly known as transducers.

Inverse transducer:

- Devices which convert an electrical quantity into non-electrical quantity is called inverse transducer.
- The name itself implies that the function of Inverse transducer is inverse of the transducer.
- In this type of transducer an electrical signal is intentionally converted into some sort of physical change.
- Example: piezoelectric crystal
- When voltage across the surface of a piezoelectric crystal is applied it changes its dimension.
- Thus electrical quantity is changed into physical quantity.
- Another example is a coil carrying current and kept in magnetic field.
- Due to interaction of current of coil with the magnetic field, it starts to rotate or translate.
- Inverse Transducer are mainly used in control system to control various process parameter that is pressure, temperature, displacement etc.

BM T46 – BIOMEDICAL SENSOERS AND TRANSDUCERS

UNIT-2

2 MARKS

1. **List the biomedical application of inductive transducer. (Sep 2020)**
   - Used to monitor the medical condition of patients such as BP monitors, heart monitors and stethoscope.
   - To measure tremor in patients suffering from Parkinson's disease.

2. **List the principle behind metallic bonded strain gauge. (Sep 2020)**

   The metallic bonded strain gauge works on the principle of electrical conductance and its dependence on the conductor's geometry. Whenever a conductor is stretched within the limits of its elasticity, it doesn't break but, gets narrower and longer.

3. **Give the formula for gauge factor. (May 2019)**

   Gauge factor (GF) or strain factor of a strain gauge is the ratio of relative change in electrical resistance R, to the mechanical strain ε. The gauge factor is defined as

   Where

$$GF = \frac{\Delta R/R}{\Delta L/L} = \frac{\Delta R/R}{\varepsilon} = 1 + 2\nu + \frac{\Delta\rho/\rho}{\varepsilon}$$

   - ε = strain
   - ν = Poisson's ratio
   - ρ = resistivity
   - ΔR = change in strain gauge resistance due axial strain and lateral strain
   - R = unstrained resistance of strain gauge

4. **Classify the characteristics of thermistor. (May 2019, May 2017)**

   Thermistors can be classified into two types:
   - **Positive temperature coefficient (PTC) thermistor:** resistance increase with increase in temperature.

- **Negative temperature coefficient (NTC) thermistor:** resistance decrease with increase in temperature.

5. Give the difference between RTD and thermistor. (Nov 2018, May 2018)

Basis for Comparison	**RTD (Resistance Temperature Detector)**	**Thermistor**
Definition	The device use for measuring the change in temperature is known as the RTD or Resistance Temperature Detector.	It is a thermal resistor whose resistance changes with the temperature.
Response Time	Slow	Fast
Material	Metals (platinum, nickel, copper, etc.)	Semiconductor
Accuracy	Less accurate.	Their accuracy is high.

6. Write the transduction principle of LVDT. (Nov 2018, May 2018)

LVDT works under the principle of mutual induction, and the displacement which is a non-electrical energy is converted into an electrical energy. And the way how the energy is getting converted is described in working of LVDT in a detailed manner.

7. What are RTD's made up of? (Nov 2017)

The RTD wire is a pure material made up of typically platinum, nickel, or copper.

8. What are inductive transducers? (Nov 2017)

- An inductive transducer (electromechanical) is an electrical device used to convert physical motion into modifying within inductance.

- Inductive transducers work on the principle of inductance change due to any appreciable change in the quantity to be measured.

9. Write a short note on strain gauge. (May 2017, May 2015)

- A Strain gauge (sometimes referred to as a Strain gage) is a sensor whose resistance varies with applied force.
- It converts force, pressure, tension, weight, etc., into a change in electrical resistance which can then be measured.
- When external forces are applied to a stationary object, stress and strain are the result.

10. Define primary type of transducer. (Nov 2016)

- The primary transducer consists of mechanical as well as the electrical devices.
- The mechanical devices of the transducer change the physical input quantities into a mechanical signal.
- This mechanical device is known as the primary transducers.

11. Give the principle of strain gauge. (Nov 2016, May 2016)

- A strain gauge works on the principle of electrical conductance and its dependence on the conductor's geometry.
- Whenever a conductor is stretched within the limits of its elasticity, it doesn't break but, gets narrower and longer.
- Similarly, when it is compressed, it gets shorter and broader, ultimately changing its resistance.

12. What is thermocouple? (May 2016)

- A thermocouple is an electrical device consisting of two dissimilar electrical conductors forming an electrical junction.
- A thermocouple produces a temperature-dependent voltage as a result of Seebeck effect, and this voltage can be interpreted to measure temperature.

13. Mention the characteristics of thermocouple. (May 2015)

- Mass

- Heat capacity
- Heat transfer co-efficient
- Surface area

14. Which transducer is used to measure room temperature of furnaces and temperature of moving masses of metal? (Nov 2015)

The thermistor or thermal transducer is used to measure room temperature of furnaces and temperature of moving masses of metal.

15. Distinguish sensors from transducers. (Nov 2015)

Basis For Comparison	Sensor	Transducer
Definition	Senses the physical changes occur in the surrounding and converting it into a readable quantity.	The transducer is a device which, when actuates transforms the energy from one form to another.
Components	Sensor itself	Sensor and signal conditioning
Function	Detects the changes and induces the corresponding electrical signals.	Conversion of one form of energy into another.
Examples	Proximity sensor, Magnetic sensor, Accelerometer sensor, Light sensor etc.	Thermistor, Potentiometer, Thermocouple, etc.

11 MARKS

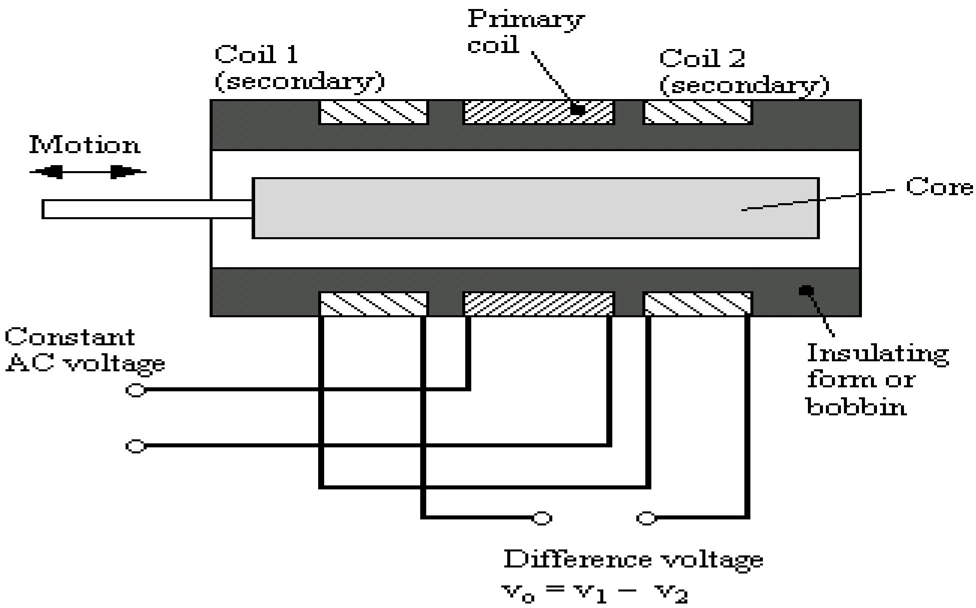
1. Write the working principle of LVDT and explain its biomedical applications. (Sep 2020, Nov 2017, May 2017, Nov 2016, May 2016, May 2015, Nov 2015)

Linear Variable Differential Transformer, LVDT is the most used inductive transducer for converting translating linear motion into electrical signal. This transducer converts a mechanical displacement proportionally into electrical signal. LVDT is a very basic transducer which is always useful in the field of instrumentation.

Principle of LVDT:

- ❖ LVDT works under the principle of mutual induction, and the displacement which is a non-electrical energy is converted into an electrical energy.
- ❖ And the way how the energy is getting converted is described in working of LVDT in a detailed manner.

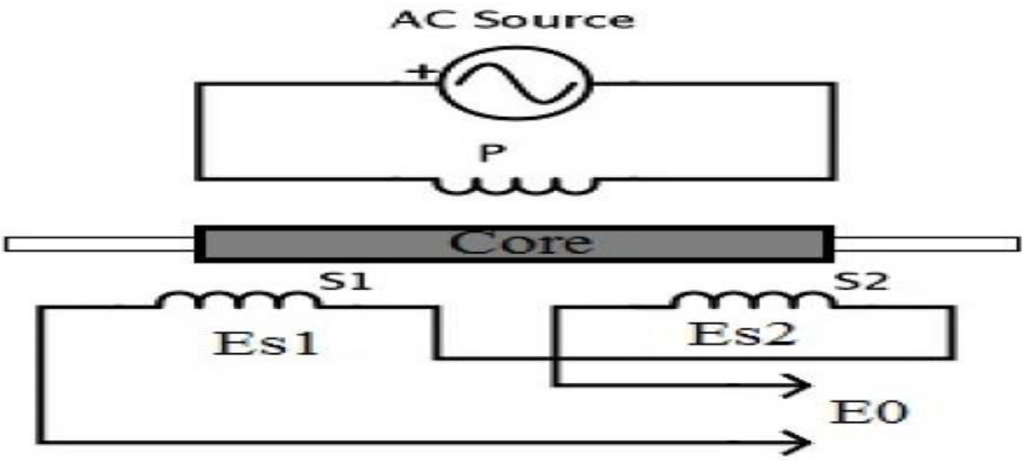
Construction of LVDT:



- ❖ LVDT consists of a cylindrical former where it is surrounded by one primary winding in the centre of the former and the two secondary windings at the sides.
- ❖ The number of turns in both the secondary windings are equal, but they are opposite to each other, i.e., if the left secondary windings is in the clockwise direction, the right secondary windings will be in the anti-clockwise direction, hence the net output voltages will be the difference in voltages between the two secondary coil.

- ❖ The two secondary coil is represented as S1 and S2. Esteem iron core is placed in the centre of the cylindrical former which can move in to and fro motion as shown in the figure.
- ❖ The AC excitation voltage is 5 to 12V and the operating frequency is given by 50 to 400 HZ.

Working of LVDT:



The LVDT will be working based on the iron core position inside the insulated former followed by three cases

Case 1: On applying an external force which is the displacement, if the core reminds in the null position itself without providing any movement then the voltage induced in both the secondary windings are equal which results in net output is equal to zero. i.e., $\mathbf{E_{S1}-E_{S2} = 0}$

Case 2: When an external force is applied and if the steel iron core tends to move in the left hand side direction then the emf voltage induced in the secondary coil is greater when compared to the emf induced in the secondary coil 2.

Therefore the net output will be $\mathbf{E_0= E_{S1}-E_{S2}}$

Case 3: When an external force is applied and if the steel iron core moves in the right hand side direction then the emf induced in the secondary coil 2 is greater when compared to the emf voltage induced in the secondary coil 1. Therefore the net output voltage will be $\mathbf{E_0= E_{S2}-E_{S1}}$

Advantages of LVDT:

- ❖ Infinite resolution is present in LVDT
- ❖ High output
- ❖ LVDT gives High sensitivity
- ❖ Very good linearity

- ❖ Ruggedness
- ❖ LVDT Provides Less friction
- ❖ Low hysteresis
- ❖ LVDT gives Low power consumption.

Disadvantages of LVDT:

- ❖ Very high displacement is required for generating high voltages.
- ❖ Shielding is required since it is sensitive to magnetic field.
- ❖ The performance of the transducer gets affected by vibrations.
- ❖ It is greatly affected by temperature changes.

Applications of LVDT:

- ❖ LVDT is used to measure displacement ranging from fraction millimetre to centimetre.
- ❖ Acting as a secondary transducer
- ❖ LVDT can be used as a device to measure force, weight and pressure, etc.

2. Illustrate about different types of strain gauges. (Sep 2020, May 2019, Nov 2018, May 2018)

The strain gauge is a passive, resistive transducer which converts the mechanical elongation and compression into a resistance change. This change in resistance takes place due to variation in length and cross sectional area of the gauge wire, when an external force acts on it.

Principle:

The strain gauge working principle is based on the fact that the electrical resistance of materials varies with deformation. A strain gauge is an example of a passive transducer that converts the mechanical displacement into electrical quantity.

We know the resistance of the conductor depends on the length and cross-sectional area.

The resistance, $R = \rho L/A$

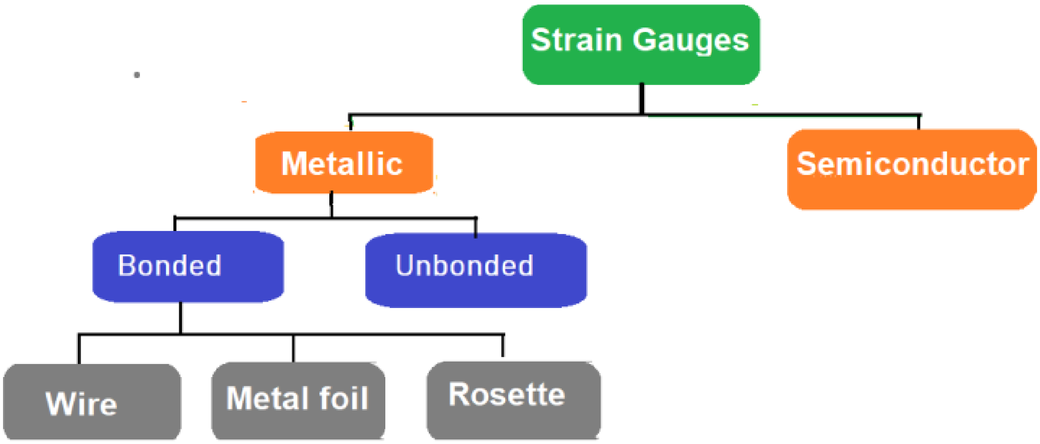
L = length of the conductor or semiconductor element.

A = Cross sectional area.

ρ = Resistivity.

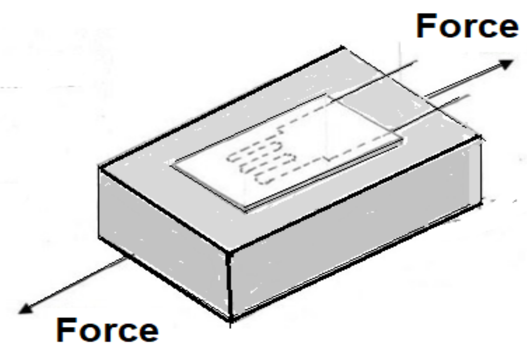
Strain gauge:

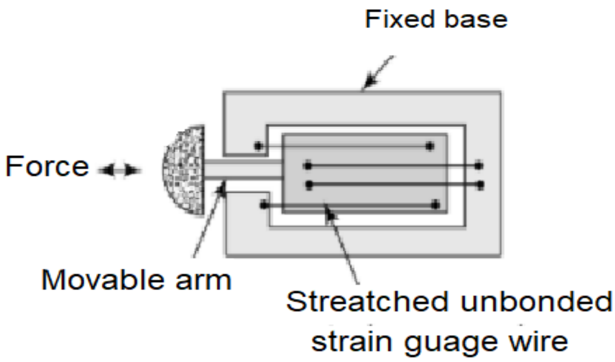
A strain gauge is a sensor whose resistance varies with an applied force. The strain gauge converts the force, pressure, tension, and weight into electrical quantity which can be measured. The electrical strain gauges measure the changes that occur in resistance, capacitance, or inductance due to the strain transferred from the work piece to the basic gauge element.



Based on mounting, metallic strain gauges are classified in as follows

<u>Bonded strain gauges</u>:



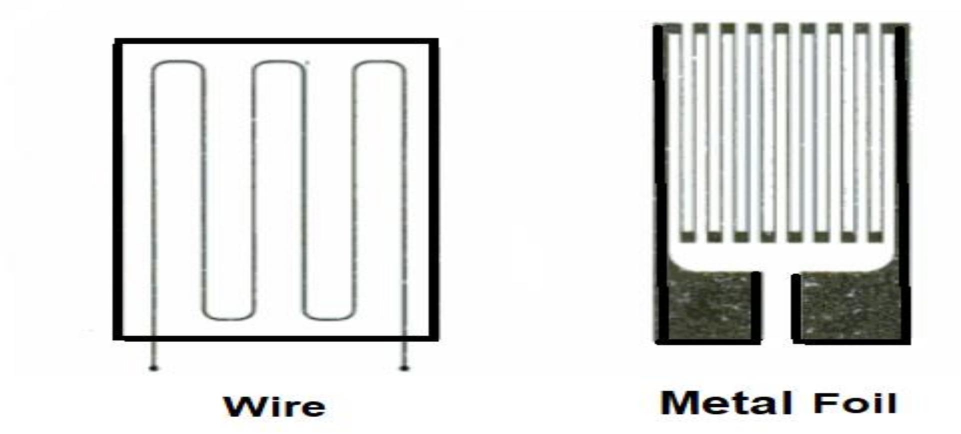


Bonded Strain gauge (fig:1) Unbonded (fig:2)

- ❖ Bonded strain gauges are so-called because they are attached to the elastic element surface.
- ❖ The most commonly used are bonded resistance type strain gauges. They are primarily used for strain analysis.
- ❖ In bonded resistance wire strain gauges resistance element is cemented to the base which may be a thin sheet of paper or a thin sheet of Bakelite or Teflon.
- ❖ The bonded strain gauge is connected to the Wheatstone bridge circuit.

WIRE STRAIN GAUGE:

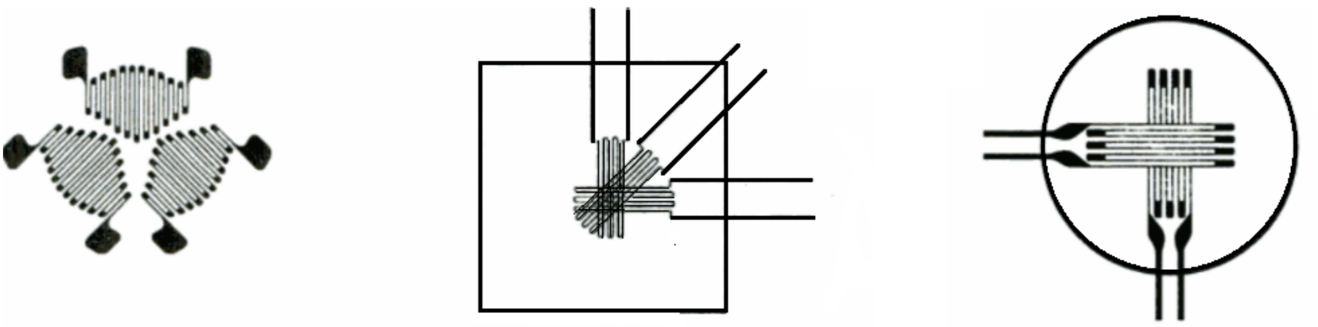
- The resistance element is in the form of wire foil or film of the material.
- In a metal bonded strain gauge a fine wire element, about 0.025 mm or less in diameter is looped back and forth on the base carrier or mounting plate.
- The base is cemented to the member subjected to the stress.
- The grid fine wire is cemented on a carrier which may be a thin sheet of paper bakelite or Teflon.



METAL FOIL:

- The strain is detected by using a metal foil. The metal foil is pasted on one side of the plastic.
- The leads are soldered to the metal foil for connecting the Wheatstone bridge.
- The metal and alloys used for the foil or wire are Constantan(Cu-Ni), Nichrome V(Ni-Cr), Isoelastic (Fe-Ni-Cr-Mn-Mo), Platinum-Tungsten(Pt-W).
- Metal Foil strain gauges exhibit a higher gauge factor than wire foil strain gauges.

ROSETTE STRAIN GAUGES:



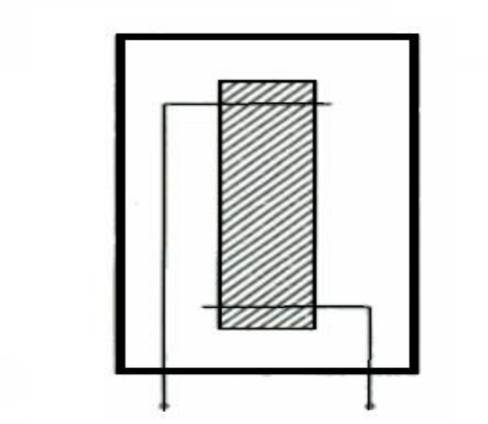
Various types of Rosette strain gauges

- Strains that are parallel to the strain axis are measured by a single strain gauge.
- Here as if there is a requirement of measurement of the strain in more than one direction, placing more than one strain gauge in a number of directions at the proper locations.

Unbonded strain gauge:

- It is exclusively used in transducer applications.
- The unbonded resistance strain gauge uses strain-sensitive wire with one end fixed or the other end attached to a movable element.
- When the strain gauge is connected to the Wheatstone bridge circuit, at initial preload, the strain and resistance of the four arms are approximately equal.
- The resultant output voltage of the bridge is equal to zero. Application of pressure causes a small displacement causes a decrease in resistance of the strain gauge.
- This results in an unbalance in the output voltage of the Wheatstone bridge which is proportional to the small displacement hence the pressure.
- Un bonded strain gauges measure the very small motion of the order of 50 micrometers and very small forces.
- The device is less robust than the bonded gauges. Unbonded wire strain gauges become less common with the advancement of the improved bonding cement.

Semiconductor strain gauges:



Semiconductor type

- The basic principle of operation of semiconductor strain gauge is the piezo-resistive effect.
- Change in value of resistance due to the change in resistivity of the semiconductor because of the strain applied.

- ❖ Semiconductor materials used are germanium and silicon.
- ❖ Semiconductor filament used has a thickness of 0.05 mm bonded on a suitable insulative material such as Teflon. Gold leads are used for making contacts.

3. Write about the construction working and biomedical applications of RTD and Thermocouple. (Nov 2018, May 2018, May 2017, May 2019, May 2016, MAY 2015)

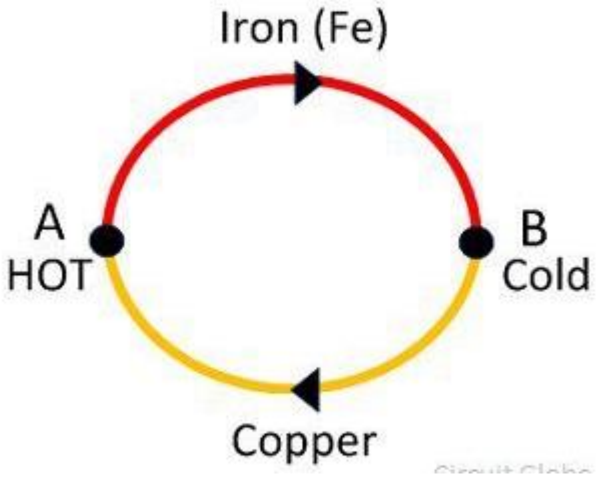
THERMOCOUPLE:

The thermocouple is a temperature measuring device. It uses for measuring the temperature at one particular point. In other words, it is a type of sensor used for measuring the temperature in the form of an electric current or the EMF.

- ❖ The thermocouple consists two wires of different metals which are welded together at the ends.
- ❖ The welded portion was creating the junction where the temperature is used to be measured.
- ❖ The variation in temperature of the wire induces the voltages.

Principle of Thermocouple

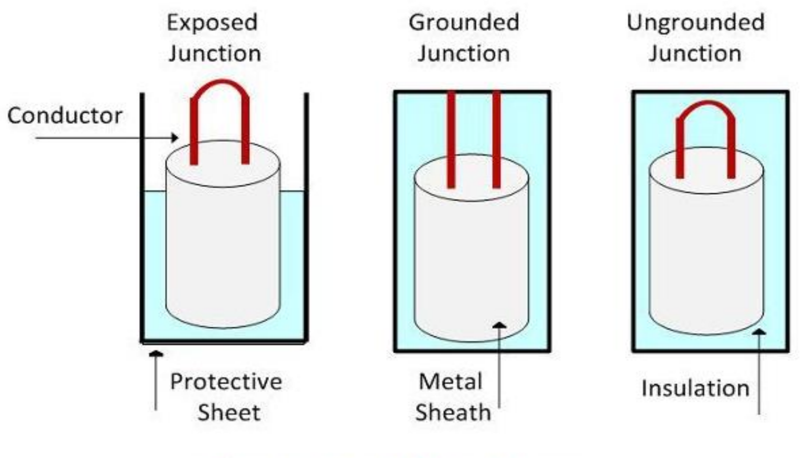
- ❖ The working principle of the thermocouple depends on the three effects.
- ❖ **Seeback Effect –** The Seeback effect occurs between two different metals. When the heat provides to any one of the metal, the electrons start flowing from hot metal to cold metal. Thus, direct current induces in the circuit.



- It is a phenomenon in which the temperature difference between the two different metals induces the potential differences between them.
- The See beck effect produces small voltages for per Kelvin of temperature.
- **Peltier Effect –** The Peltier effect is the inverse of the Seebeck effect. The Peltier effect state that the temperature difference can be created between any two different conductors by applying the potential difference between them.
- **Thompson Effect –** The Thompson effect state that when two dissimilar metals join together and if they create two junctions then the voltage induces the entire length of the conductor because of the temperature gradient.
- The temperature gradient is a physical term which shows the direction and rate of change of temperature at a particular location.

<u>Construction of Thermocouple</u>

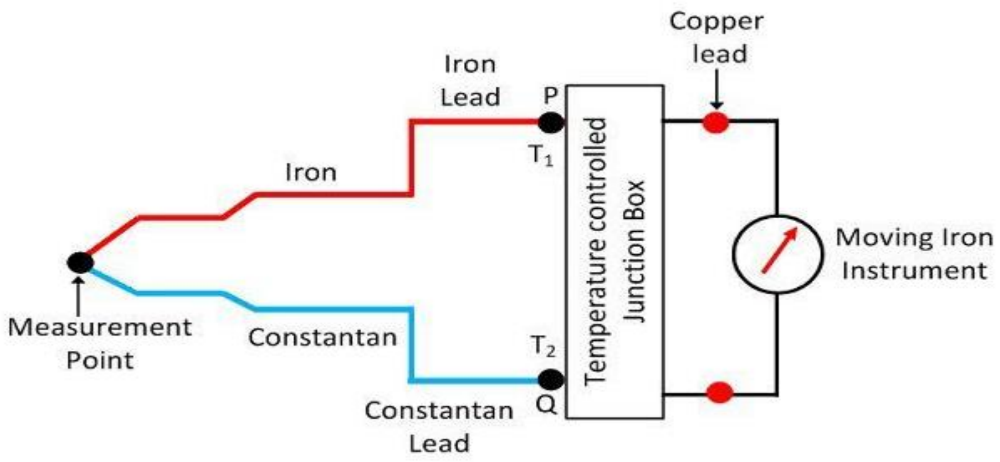
- The thermocouple consists two dissimilar metals. These metals are welded together at the junction point.
- This junction considers as the measuring point. The junction point categorises into three types.
- **Ungrounded Junction –** In ungrounded junction, the conductors are entirely isolated from the protective sheath. It is used for high-pressure application works. The major advantage of using such type of junction is that it reduces the effect of the stray magnetic field.



Thermocouple Junctions

- **Grounded Junction** – In such type of junction the metals and protective sheath are welded together. The grounded junction use for measuring the temperature in the corrosive environment. This junction provides resistance to the noise.
- **Exposed Junction** – Such type of junction uses in the places where fast response requires. The exposed junction is used for measuring the temperature of the gas.
- The material use for making the thermocouple depends on the measuring range of temperature.

Working of Thermocouple



Iron Constonant Thermocouple

- The circuit consists of two dissimilar metals.
- These metals are joined together in such a manner that they are creating two junctions.
- The metals are bounded to the junction through welding.
- Let the P and Q are the two junctions of the thermocouples.
- The T1 and T2 are the temperatures at the junctions. As the temperature of the junctions is different from each other, the EMF generates in the circuit.
- If the temperature at the junction becomes equal, the equal and opposite EMF generates in the circuit, and the zero current flows through it.
- If the temperatures of the junction become unequal, the potential difference induces in the circuit.
- The magnitude of the EMF induces in the circuit depends on the types of material used for making the thermocouple.
- The total current flowing through the circuit is measured through the measuring devices.

- The EMF induces in the thermocouple circuit is given by the equationequation-for-thermocouples.
- Where Δθ – temperature difference between the hot thermocouple junction and the reference thermocouple junction.
- a, b – constants

Measurement of Thermocouple Output

- The output EMF obtained from the thermocouples can be measured through the following methods.
- **Multimeter –** It is a simpler method of measuring the output EMF of the thermocouple. The multimeter is connected to the cold junctions of the thermocouple. The deflection of the multimeter pointer is equal to the current flowing through the meter.
- **Potentiometer –** The output of the thermocouple can also be measured with the help of the DC potentiometer.
- **Amplifier with Output Devices –** The output obtains from the thermocouples is amplified through an amplifier and then feed to the recording or indicating instrument

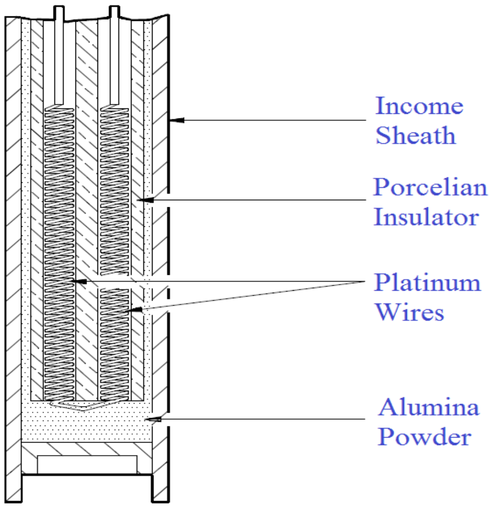
RESISTANCE TEMPERATURE DETECTORS (RTD):

Construction:

- The RTD incorporates pure metals or certain alloys that increase in resistance as temperature increases and, conversely, decrease in resistance as temperature decreases.
- RTDs act somewhat like an electrical transducer, converting changes in temperature to voltage signals by the measurement of resistance.
- The metals that are best suited for use as RTD sensors are pure, of uniform quality, stable within a given range of temperature, and able to give reproducible resistance-temperature readings.
- Only a few metals have the properties necessary for use in RTD elements.
- RTD elements are normally constructed of platinum, copper, or nickel.
- These metals are best suited for RTD applications because of their linear resistance-temperature characteristics their high coefficient of resistance, and their ability to withstand repeated temperature cycles.
- RTD elements are usually long, spring-like wires surrounded by an insulator and enclosed in a sheath of metal. Figure 2 shows the internal construction of an RTD.

- This particular design has a platinum element that is surrounded by a porcelain insulator.
- The insulator prevents a short circuit between the wire and the metal sheath.
- Inconel, a nickel-iron-chromium alloy, is normally used in manufacturing the RTD sheath because of its inherent corrosion resistance.
- When placed in a liquid or gas medium, the Inconel sheath quickly reaches the temperature of the medium.
- The change in temperature will cause the platinum wire to heat or cool, resulting in a proportional change in resistance.

Internal Construction of a RTD



<u>RTD Working Principle</u>

- As we know that every metal has a definite value of resistance at a particular temperature.
- This value of resistance changes with the change in its temperature and is very predictable.
- So we can calculate the temperature of metals by knowing its resistance.
- The resistance of an RTD at any temperature (RT) can be calculated from the following formula:

  $RT = R_o(1 + \alpha T)$

  Where, Ro = resistance of RTD at 0^oC.

  α = temperature coefficient of resistance

  for PT $_{100}$, $R_o = 100$ ohms, $\alpha = 0.00385$ ohms/^oC.

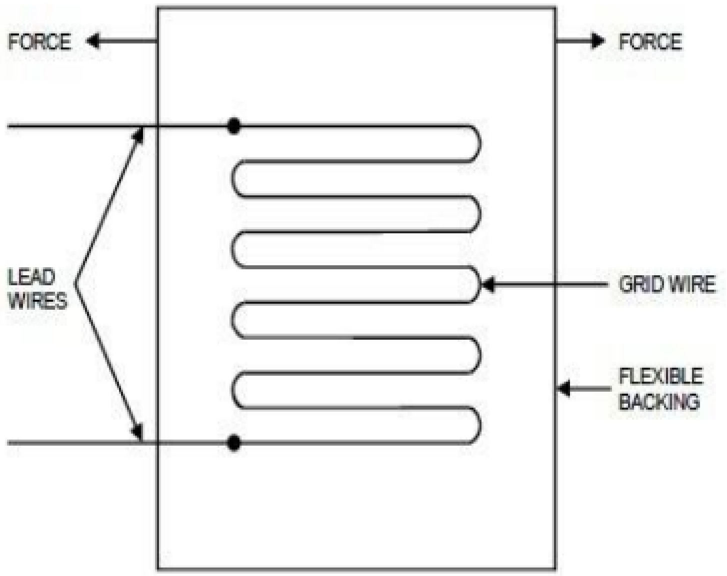
- The resistance temperature detector uses the change in electrical resistance of the sensing element to determine its temperature.
- This is the basic resistance temperature detector working principle.
- The metals having a positive temperature coefficient is used for the construction of RTDs.
- Mostly, platinum is used. It is a standard material for the RTDs.
- It is used mostly for this purpose because:
  - It can withstand high temperatures.
  - Its stability is excellent.
  - It is a noble metal. So it is very less susceptible to contamination.
  - Its temperature resistance characteristics are most linear for the wide range of temperature.
  - Therefore, it has a wide operating range (from – 200oC to + 850oC).
- Apart from platinum, some other metals like copper and nickel are also used for the construction of RTDs.
- The nickel has greater sensitivity due to its higher temperature coefficient.

4. Explain the construction of the wire wound strain gauge. Derive an expression for gauge factor of a strain gauge. (Nov 2017)

- A Strain gauge (sometimes referred to as a Strain gage) is a sensor whose resistance varies with applied force. Strain Gauge or Strain Gage was invented in 1938 by Edward Simmons and Arthur C. Ruge.
- It is one of the significant sensors used in the geotechnical field to measure the amount of strain on any structure (Dams, Buildings, Nuclear Plants, Tunnels, etc.).
- Wire wounded strain gauges: In an electrical resistance strain gauge, the device consists of a thin wire placed on a flexible paper tissue and is attached to a variety of materials to measure the strain of the material.
- This change in resistance is proportional to the strain and is measured using a Wheatstone bridge.
- There are two main classes of wire wound strain gauges:
  - ➢ Bonded strain gauge
  - ➢ Unbonded strain gauge

Bonded strain gauge:

- These gauges are directly bonded (that is pasted) on the surface of the structure under study.
- Hence they are termed as bonded strain gauges. Along with the construction of transducers, a bonded metal wire strain gauge is used for stress analysis.
- A resistance wire strain gauge has a wire of diameter 0.25mm or less.



- The grid of fine resistance wire is cemented to carrier.
- It can be a thin sheet of paper, Bakelite or a sheet of Teflon. To prevent the wire from any mechanical damage, it covered on top with a thin sheet of material.
- The spreading of wire allows us to have a uniform distribution of stress over the grid. The carrier is bonded with an adhesive material.
- Due to this, a good transfer of strain from carrier to a grid of wires is achieved.
- A resistance wire strain gauge must possess the following characteristics in order to have desirable results
  1. The strain gauge should have a high value of gauge factor. As high gauge factor indicates a large change in resistance, which leads to high sensitivity.
  2. The gauge resistance should be high so as to minimize the effect of undesirable variations of resistance in measurement circuits.
- Typically, the resistance of strain gauges is 120Ω, 350Ω, 1000Ω.
- But a high resistance value results in lower sensitivity.
- Thus to have higher sensitivity, higher bridge voltages have to be used.

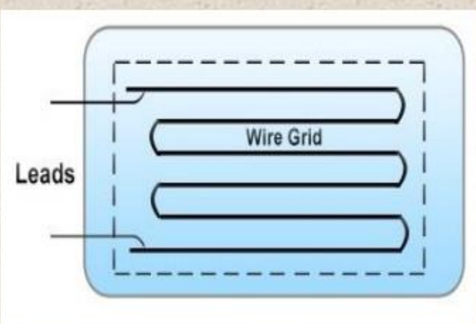
- ❖ The strain gauge should have low resistance temperature coefficient.
- ❖ It should possess linear characteristics in order to have the constancy of calibration over its entire range.
- ❖ Strain gauges must have a good frequency response.
- ❖ The linearity should be maintained within accuracy limits.

Various types of bonded strain gauges are:

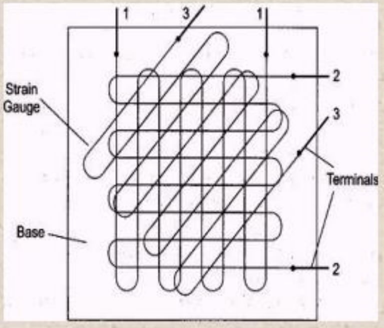
1. Grid type:
2. Rossette type:

- ❖ If the axis of the strain in a component is unknown, Strain Gauge Transducer types may be used to determine the exact direction.
- ❖ The standard procedure is to place several gauges at a point on the member's surface, with known angles between them.
- ❖ The magnitude of strain in each individual gauge is measured, and used in the geometrical determination of the strain in the member.
- ❖ Shows a three-element strain gauge, called a Rossette gauge, in which the angle between any two longitudinal gauge axes is 45°.

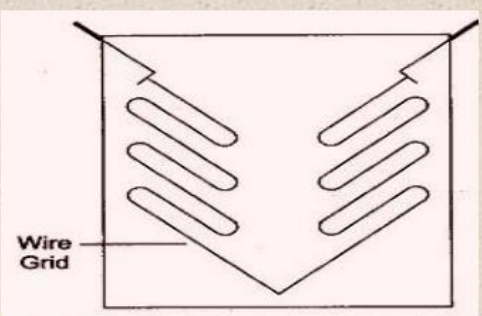
3. Torque type:
4. Helical type:



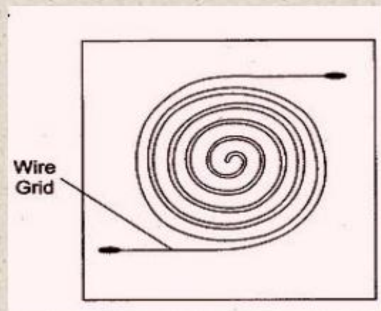
Grid type



Rossette type



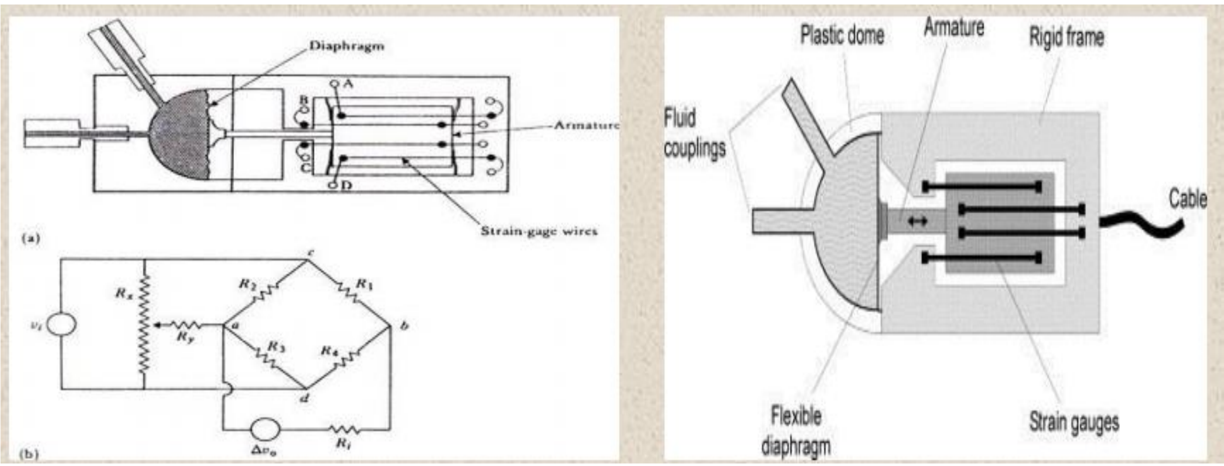
Torque type



Helical type

Unbonded strain gauge:

- ❖ It is a type of gauge in which a wire is stretched in an insulating medium in between two points.
- ❖ The insulating medium can be air.
- ❖ The wire can be made of alloys such as copper-nickel, chrome nickel, nickel-iron having a diameter of about 0.003 mm.
- ❖ The gauge factor for this category of the strain gauge is about 2 to 4 and capable to withstand a force of 2MN.
- ❖ These are almost exclusively used in transducer applications where preloaded resistance wires are connected in a Wheatstone bridge configuration.
- ❖ The arrangement of unbonded strain gauges consists of the following. Two frames P and Q carrying rigidly fixed insulated pins as shown in diagram.
- ❖ These two frames can move relative with respect to each other and they are held together by a spring loaded mechanism.
- ❖ A fine wire resistance strain gauge is stretched around the insulated pins.
- ❖ The strain gauge is connected to a wheat stone bridge.



Operation of Unbonded strain gauges:

- ❖ When a force is applied on the structure under study (frames P & Q), frames P moves relative to frame Q, and due to this strain gauge will change in length and cross section.
- ❖ That is, the strain gauge is strained. This strain changes the resistance of the strain gauge and this change in resistance of the strain gauge is measured using a wheat stone bridge.
- ❖ This change in resistance when calibrated becomes a measure of the applied force and change in dimensions of the structure under study.

Application of Unbonded strain gauge:

- Unbonded strain gauge is used in places where the gauge is to be detached and usedagain and again.
- Unbonded strain gauges are used in force, pressure and acceleration measurement.

Advantages of Unbonded strain gauge:

- The range of this gauge is +/- 0.15% strain.
- This gauge has a very high accuracy.
- Limitation of unbonded strain gauges
- It occupies more space.

Gauge factor :

Gauge factor (GF) or strain factor of a strain gauge is the ratio of relative change in electrical resistance R, to the mechanical strain ε.

The gauge factor is defined as

$$GF = \frac{\Delta R/R}{\Delta L/L} = \frac{\Delta R/R}{\varepsilon} = 1 + 2\nu + \frac{\Delta\rho/\rho}{\varepsilon}$$

- ε = strain = $\Delta L/L_0$

  ΔL = absolute change in length

  L_0 = original length
- ν = Poisson's ratio
- ρ = resistivity
- ΔR = change in strain gauge resistance due axial strain and lateral strain
- R = unstrained resistance of strain gauge

5. (a) Explain the characteristics of a thermistor. (Nov 2016)

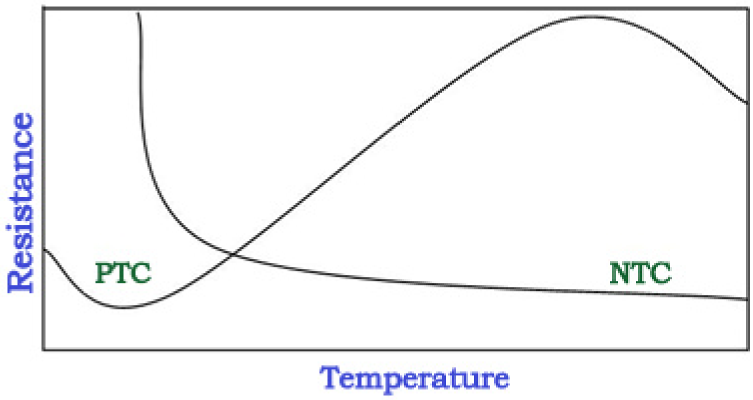
- A thermistor is a type of resistor whose resistance strongly depends on temperature. The word thermistor is a combination of words “thermal” and “resistor”.
- A thermistor is a temperature-sensing element composed of sintered semiconductor material and sometimes mixture of metallic oxides such as Mn, Ni, Co, Cu and Fe,

which exhibits a large change in resistance proportional to a small change in temperature.

- ❖ Pure metals have positive temperature coefficient of resistance, alloys have nearly equal zero temperature coefficient of resistance and semi conductors have negative temperature coefficient of resistance.

Thermistor characteristics:

- ❖ Resistance increase with increase in temperature for PTC and resistance decrease with increase in temperature for NTC.



- ❖ The thermistor exhibits a highly non-linear characteristic of resistance vs temperature.

PTC AND NTC Thermistors:

- ❖ PTC thermistors can be used as heating elements in small temperature controlled ovens.
- ❖ NTC thermistors can be used as inrush current limiting devices in power supply circuits.
- ❖ Inrush current refers to maximum, instantaneous input current drawn by an electrical device when first turned on.
- ❖ Thermistors are available in variety of sizes and shapes; smallest in size are the beads with a diameter of 0.15mm to 1.25mm.
- ❖ There are two fundamental ways to change the temperature of thermistor internally or externally.
- ❖ The temperature of thermistor can be changed externally by changing the temperature of surrounding media and internally by self-heating resulting from a current flowing through the device.
- ❖ The dependence of the resistance on temperature can be approximated by following equation,

$$R = R_0 e^{\beta\left(\frac{1}{T} - \frac{1}{T_0}\right)} \quad \text{-----------------------------------} \ (1)$$

Where,

R is the resistance of thermistor at the temperature T (in K)

R0 is the resistance at given temperature T0 (in K)

β is the material specific-constant

- The material specific-constant of a NTC thermistor is a measure of its resistance at one temperature compared to its resistance at a different temperature.
- Its value may be calculated by the formula shown below and is expressed in degrees Kelvin (°K).

Differentiating (1) with respect to T, we get

$$\frac{dR}{dT} = -\frac{R\beta}{T^2}$$

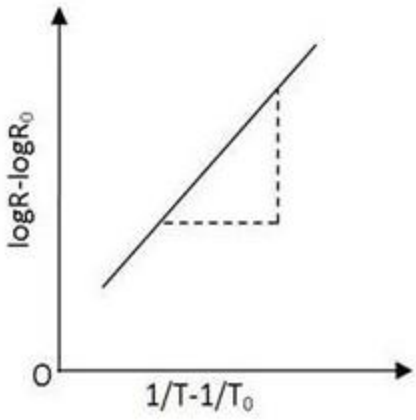
$$\alpha = -\frac{dR}{RdT} \quad \text{is the temp coefficient of resistance.}$$

Taking log of (1) and simplifying we get,

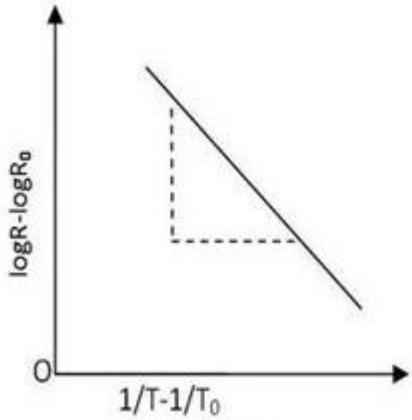
$$\beta = \frac{\log R - \log R_0}{\frac{1}{T} - \frac{1}{T_0}} \quad \text{-----------------------------------} \ (2)$$

$$\text{so} \quad \alpha = -\frac{\beta}{T^2} \quad \text{-----------------------------------} \ (3)$$

A graph plotted with $\log R - \log R_0$ in Y axis and $\frac{1}{T} - \frac{1}{T_0}$ in X axis for NTC and PTC is shown below. The slope of graph gives value of β.



1. NTC



2. PTC

(b) Define capacitive transducer. Discuss with variation of overlapping area of plates.

Capacitive Transducer:

- The capacitive transducer is used for measuring the displacement, pressure and other physical quantities.
- It is a passive transducer that means it requires external power for operation. The capacitive transducer works on the principle of variable capacitances.
- The capacitance of the capacitive transducer changes because of many reasons like overlapping of plates, change in distance between the plates and dielectric constant.
- The capacitive transducer contains two parallel metal plates. These plates are separated by the dielectric medium which is air, material, gas or liquid.
- In the normal capacitor the distance between the plates are fixed, but in capacitive transducer the distance between them are varied.
- The capacitive transducer uses the electrical quantity of capacitance for converting the mechanical movement into an electrical signal.
- The input quantity causes the change of the capacitance which is directly measured by the capacitive transducer.
- The capacitors measure both the static and dynamic changes. The displacement is also measured directly by connecting the measurable devices to the movable plate of the capacitor. It works on with both the contacting and non-contacting modes.

Principle of Operation:

- The equations below express the capacitance between the plates of a capacitor

  Capacitive equation-1

$$C = \varepsilon A/d$$

$$C = \varepsilon_r \varepsilon_0 A/d$$

Where, A – overlapping area of plates in m2

d – the distance between two plates in meter

ε – permittivity of the medium in F/m

εr – relative permittivity

ε0 – the permittivity of free space

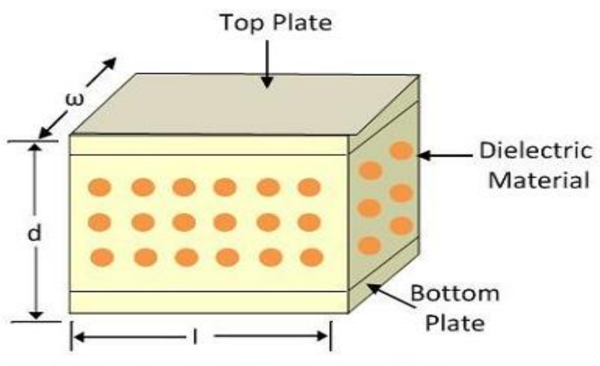
- The change in capacitance occurs because of the physicals variables like displacement, force, pressure, etc.
- The capacitance of the transducer also changes by the variation in their dielectric constant which is usually because of the measurement of liquid or gas level.
- The capacitance of the transducer is measured with the bridge circuit. The output impedance of transducer is given as

$$X_c = 1/2\pi f c$$

Where, C – capacitance

f – frequency of excitation in Hz.

- The capacitive transducer is mainly used for measurement of linear displacement.



Parallel Plate Capacitive Transducer

- The capacitive transducer uses the following three effects.
- Variation in capacitance of transducer is because of the overlapping of capacitor plates.
- The change in capacitance is because of the change in distances between the plates.
- The capacitance changes because of dielectric constant.

- During the transducer using the change in the Area of Plates - The capacitance is directly proportional to the area of the plates, The capacitance changes correspondingly with the change in the position of the plates.
- The following methods are used for the measuring displacement.

CAPACITIVE-TRANSDUCER-WITH-DISPLACEMENT:

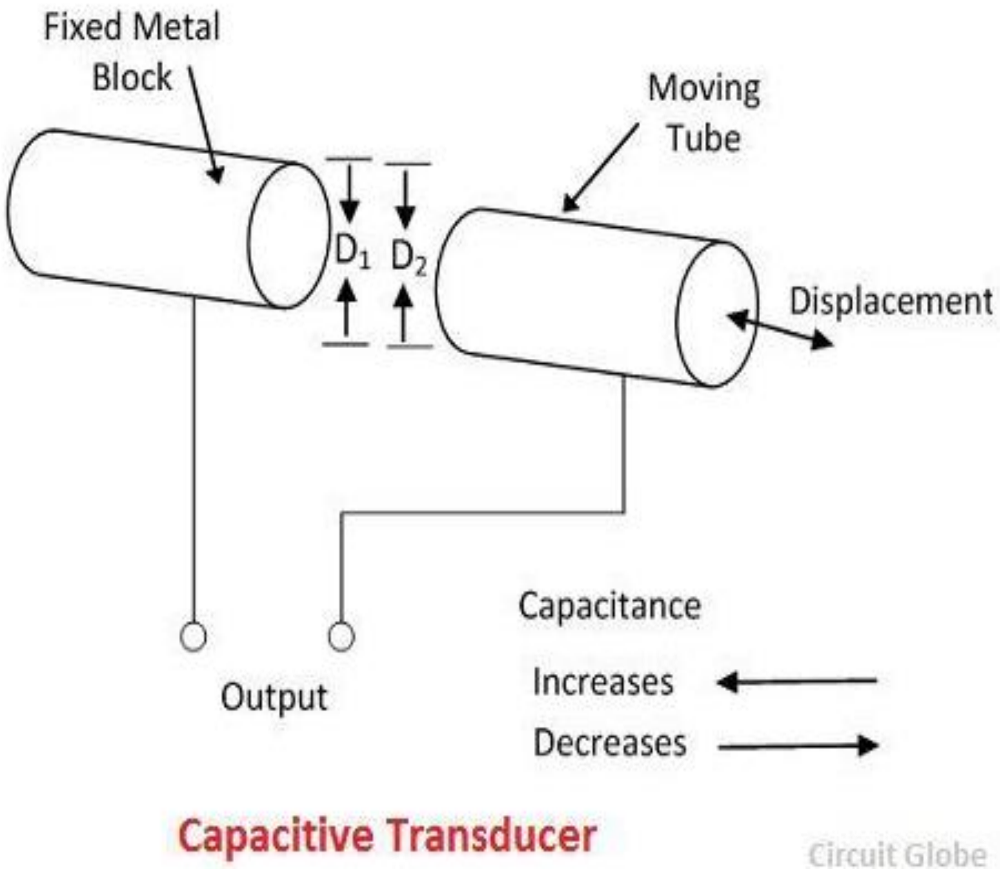
- The capacitive transducers are used for measuring the large displacement approximately from 1mm to several cms.
- The area of the capacitive transducer changes linearly with the capacitance and the displacement.
- Initially, the nonlinearity occurs in the system because of the edges. Otherwise, it gives the linear response.

The capacitance of the parallel plates is given as

$$C = \frac{\varepsilon A}{d} = \frac{\varepsilon x \omega}{d} F$$

Where, x – the length of overlapping part of plates

ω – the width of overlapping part of plates.



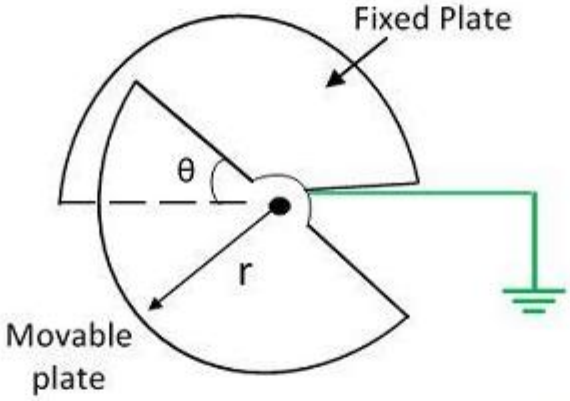
❖ The sensitivity of the displacement is constant, and therefore it gives the linear relation between the capacitance and displacement.

$$S = \frac{\partial C}{\partial x} = \varepsilon \frac{\omega}{d} F/m$$

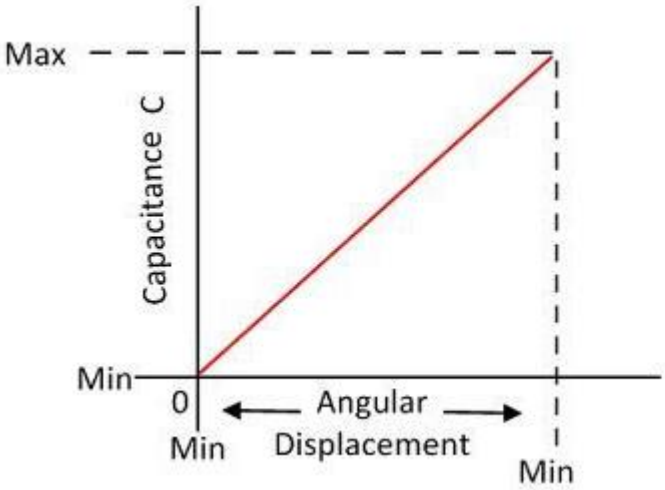
❖ The capacitive transducer is used for measuring the angular displacement. It is measured by the movable plates shown below.

❖ One of the plates of the transducer is fixed, and the other is movable.

<u>ANGULAR-CAPACITIVE-TRANSDUCER</u>



The phasor diagram of the transducer is shown in the figure below.



❖ The angular movement changes the capacitance of the transducers.

❖ The capacitance between them is maximum when these plates overlap each other.

❖ The maximum value of capacitance is expressed as

$$C_{max} = \frac{\varepsilon A}{d} = \frac{\pi \varepsilon r^2}{2d}$$

❖ The capacitance at angle θ is given expressed as,

$$C = \frac{\varepsilon \theta r^2}{2d}$$

θ – angular displacement in radian.

❖ The sensitivity for the change in capacitance is given as

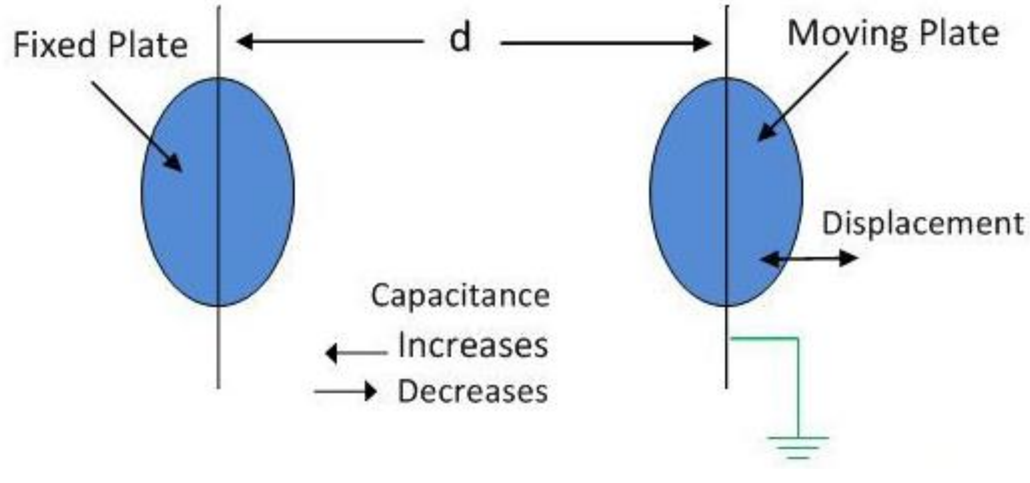
$$S = \frac{\partial C}{\partial \theta} = \frac{\varepsilon r^2}{2d}$$

❖ The 180° is the maximum value of the angular displacement of the capacitor.

❖ During the transducer used to change in distance between the plates – The capacitance of the transducer is inversely proportional to the distance between the plates.

❖ The one plate of the transducer is fixed, and the other is movable. The displacement which is to be measured links to the movable plates.

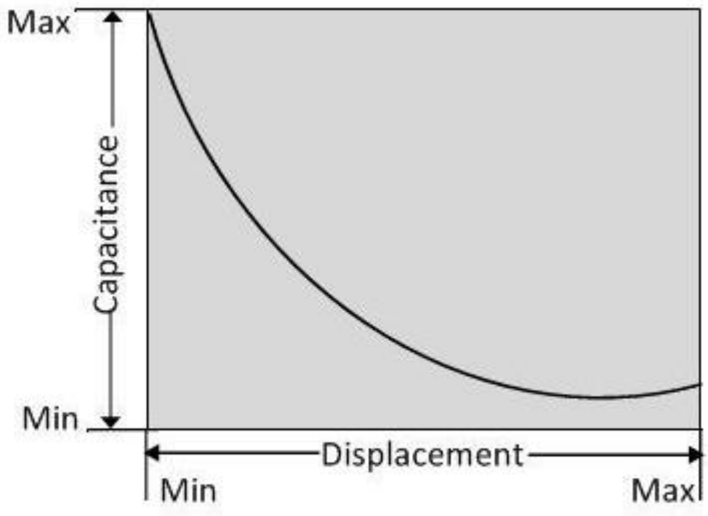
DISPLACEMENT-CAPACITIVE-TRANSDUCER



❖ The capacitance is inversely proportional to the distance because of which the capacitor shows the nonlinear response.

❖ Such type of transducer is used for measuring the small displacement. The phasor diagram of the capacitor is shown in the figure below.

❖ The sensitivity of the transducer is not constant and varies from places to places.



6. What are the characteristics of thermistor? Explain its application as incubator. (Nov 2015)

<u>THERMISTOR:</u>

- ❖ A thermistor is a type of resistor whose resistance strongly depends on temperature. The word thermistor is a combination of words "thermal" and "resistor".
- ❖ A thermistor is a temperature-sensing element composed of sintered semiconductor material and sometimes mixture of metallic oxides such as Mn, Ni, Co, Cu and Fe, which exhibits a large change in resistance proportional to a small change in temperature.
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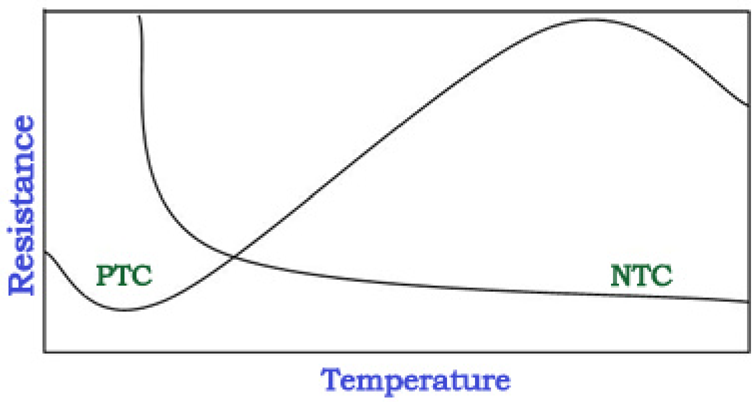

- Resistance increase with increase in temperature for PTC and resistance decrease with increase in temperature for NTC.
- The thermistor exhibits a highly non-linear characteristic of resistance vs temperature.

TYPES:

PTC and NTC

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- NTC thermistors can be used as inrush current limiting devices in power supply circuits.
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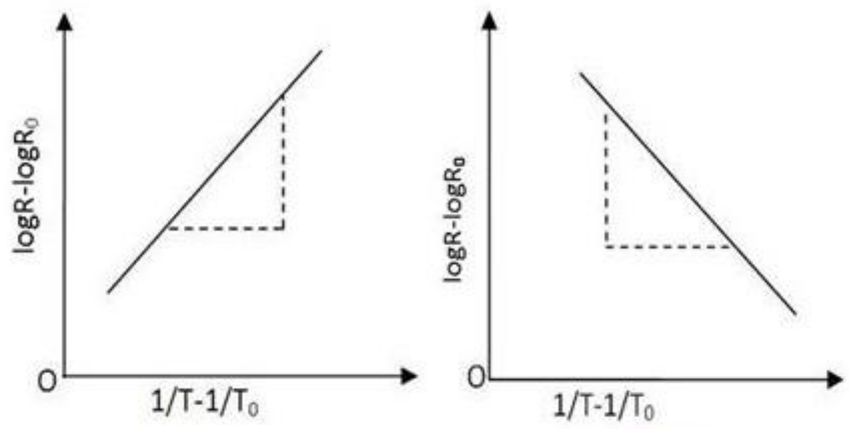


1. NTC **2. PTC**

APPLICATION OF INCUBATOR

- Incubators have a wide range of applications in various areas including cell culture, pharmaceutical studies, hematological studies, and biochemical studies.
- Incubators are used to grow microbial culture or cell cultures.
- Incubators can also be used to maintain the culture of organisms to be used later.

BM T46 – BIOMEDICAL SENSORS AND TRANSDUCERS

UNIT-3

2 MARKS

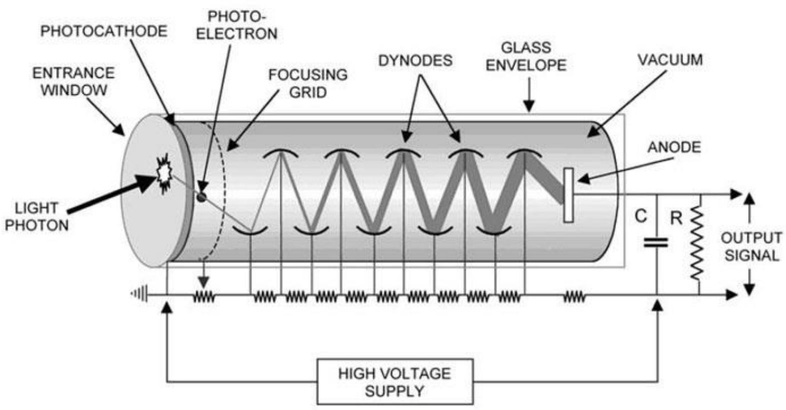
1. Give the principle of photodiode. (Sep 2020)

- ❖ The working principle of a photodiode is, when a photon of ample energy strikes the diode and it makes a couple of an electron-hole. This mechanism is also called the inner photoelectric effect.
- ❖ Light energy is converted into electrical energy. Photon current generated is proportional to the absorbed light energy.

2. Write the application of photoelectric transducer. (Sep 2020, May 2019)

- ❖ These transducers are used in biomedical applications
- ❖ Pickups of pulse
- ❖ Pneumograph respiration
- ❖ Measure blood pulsatile volume changes
- ❖ Records Body movements.

3. Draw a PMT. (May 2019)



4. Give the classification of ultrasound transducers. (Nov 2018, May 2018)

Mainly there are three types of ultrasound transducers. They are

- ❖ Linear

- Convex
- Phased array

Other types such as the pencil, endocavity and transesophageal.

5. Write the principle of photoelectric transducer. (Nov 2018, May 2018, May 2017)

Photoelectric transducers are based on the principle of conversion of light energy into electrical energy. This is done by causing the radiation to fall on a photosensitive element and measuring the electrical current so generated with a sensitive galvanometer directly or after suitable amplification.

6. Give the construction of an ultrasound transducer. (Nov 2017)

For taking an ultrasound imaging, we need a transducer probe, transducer pulse control, CPU, display, keyboard, disc storage device, printer.

- Transducer probe - sending and receiving the sound waves.
- Transducer pulse control - changes the amplitude , frequency and duration of the pulses emitted from the transducer probe.
- CPU - computer that does all the calculation and contains the electrical power supply for itself.
- Display - display the image.
- Keyboard - Inputs the data and take measurement from the display.
- Disc storage device - stores the images.
- Printer - print the image.

7. List the applications of photodiode.(Nov 2017)

- These diodes are used in consumer electronics devices like smoke detectors, compact disc players, and televisions and remote controls in VCRs.
- In other consumer devices like clock radios, camera light meters, and street lights, photoconductors are more frequently used rather than photodiodes.
- Photodiodes are frequently used for exact measurement of the intensity of light in science & industry. Generally, they have an enhanced, more linear response than photoconductors.

- ❖ Photodiodes are also widely used in numerous medical applications like instruments to analyze samples, detectors for computed tomography, and also used in blood gas monitors.

8. What is half cell potential? (May 2017, May 2015)

The voltage developed between an electrode and electrolyte gel at their interface, is called the half cell potential or electrode potential.

This is due to two reasons:

- ❖ Passage of ions from the metal electrode into electrolyte solution.
- ❖ Combination of metallic ions in the electrolyte with the electrons in the electrode metal.

9. What is photoelectric transducer and list its types? (Nov 2016)

The photoelectric transducer can be defined as, a transducer which changes the energy from the light to electrical. It can be designed with the semiconductor material.

These transducers are classified into five types which include the following

- ❖ Photo emissive Cell
- ❖ Photodiode
- ❖ Phototransistor
- ❖ Photo-voltaic cell
- ❖ Photoconductive Cell

10. What is called Piezo electric transducer? (Nov 2016, May 2015)

The Piezoelectric transducer is an electroacoustic transducer use for conversion of pressure or mechanical stress into an alternating electrical force. It is used for measuring the physical quantity like force, pressure, stress, etc., which is directly not possible to measure.

11. How does a phototransistor work? (May 2016)

- A normal transistor includes an emitter, base, and collector terminals. The collector terminal is biased positively relating to the emitter terminal & the BE junction is reverse biased.
- A phototransistor activates once the light strikes the base terminal & the light triggers the phototransistor by allowing the configuration of hole-electron pairs as well as the current flow across the emitter or collector. When the current increases, then it is concentrated as well as changed into voltage.
- Generally, a phototransistor doesn't include a base connection. The base terminal is disconnected as the light is used to allow the flow of current to supply throughout the phototransistor.

12. Give few applications of ultrasonic transducers. (May 2016)

- These transducers have many applications in different fields like industrial, medical, etc. These are having more applications because of ultrasonic waves.
- This helps finds the targets, measure the distance of the objects to the target, to find the position of the object, to calculate the level also the ultrasonic transducers are helpful.
- In the medical field, the ultrasonic transducer is having the applications in diagnostic testing, surgical devices while treating cancer, internal organ testing, heart checkups, eyes and uterus checkups ultrasonic transducers are useful.

13. Differentiate photoelectric sensors from piezoelectric sensors. (Nov 2015)

Photoelectric sensors	**Piezoelectric sensors**
A photoelectric sensor, or photo eye, is a device used to detect the distance, absence, or presence of an object by using a light transmitter, often infrared, and a photoelectric receiver. Photoelectric sensors use a beam of light to detect the presence or absence of an object.	A piezoelectric sensor, also known as a piezoelectric transducer, is a device that uses the piezoelectric effect to measure changes in pressure, acceleration, temperature, strain or force by converting these into an electrical charge.
They are used extensively in industrial manufacturing. This technology is used to	The high sensitivity of piezoelectric transducers makes them

identify size and contrast of an object.	useful in microphones, where they convert sound pressure into electric voltage, in precision balances, in accelerometers and motion detectors, and as generators and detectors of ultrasound.

14. List the features of spectrum analyzers. (Nov 2015)

- ❖ A spectrum analyzer is a device that measures the power spectrum. It is often used to examine the components of a waveform, whether it is electrical, acoustic or optical in form.
- ❖ There are basically two kinds of spectrum analyzers, the analog and the digital.
- ❖ It also displays the received signal and compares the bandwidth to the frequency.
- ❖ Spectrum analyzers are also useful in analyzing amplitude against the frequency.
- ❖ Amplitude is normally measured in power or in dBm instead of volts, which is what is normally used in most spectrum analyzer.

11 MARKS

1. Explain the working of a photoconductive detector. (Sep 2020, May 2016, May 2015)

The photoconductive cell is a two terminal semiconductor device whose terminal resistance will vary (linearly) with the intensity of the incident light. For obvious reasons, it is frequently called a photo resistive device.

Principle:

It is based on the principle of variation of conductivity (i.e.) conductivity changes according to the wavelength and intensity of incident radiation.

LDR:

- ❖ Photoconductive cell is also called as LDR.
- ❖ A Light Dependent Resistor (also known as a photo resistor or LDR) is a device whose resistivity is a function of the incident electromagnetic radiation. Hence, they are light sensitive devices. They are also called as photoconductors, photoconductive cells or simply photocells.

- They are made up of semiconductor materials that have high resistance. There are many different symbols used to indicate a photo resistor or LDR, one of the most commonly used symbols is shown in the figure below. The arrow indicates light falling on it.

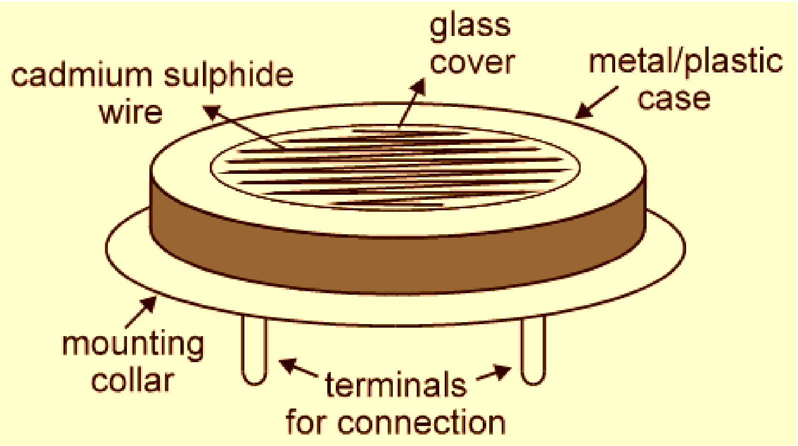
Characteristics of Photo resistor (LDR):

- Photo resistor LDR's are light-dependent devices whose resistance is decreased when light falls on them and that is increased in the dark. When a light dependent resistor is kept in dark, its resistance is very high. This resistance is called as dark resistance.
- It can be as high as 1012 Ω and if the device is allowed to absorb light its resistance will be decreased drastically. If a constant voltage is applied to it and the intensity of light is increased the current starts increasing.
- Photocells or LDR's are nonlinear devices. Their sensitivity varies with the wavelength of light incident on them. Some photocells might not at all response to a certain range of wavelengths. Based on the material used different cells have different spectral response curves.
- When light is incident on a photocell it usually takes about 8 to 12 ms for the change in resistance to take place, while it takes one or more seconds for the resistance to rise back again to its initial value after removal of light. This phenomenon is called a resistance recovery rate. This property is used in audio compressors.
- Also, LDR's are less sensitive than photodiodes and phototransistors. (A photo diode and a photocell (LDR) are not the same, a photo-diode is a pn junction semiconductor device that converts light to electricity, whereas a photocell is a passive device, there is no pn junction in this nor it "converts" light to electricity).
- LDR is a semiconductor device in which the resistance depends on the intensity of light. Resistance is inversely proportional to the intensity of incident light.

Construction:

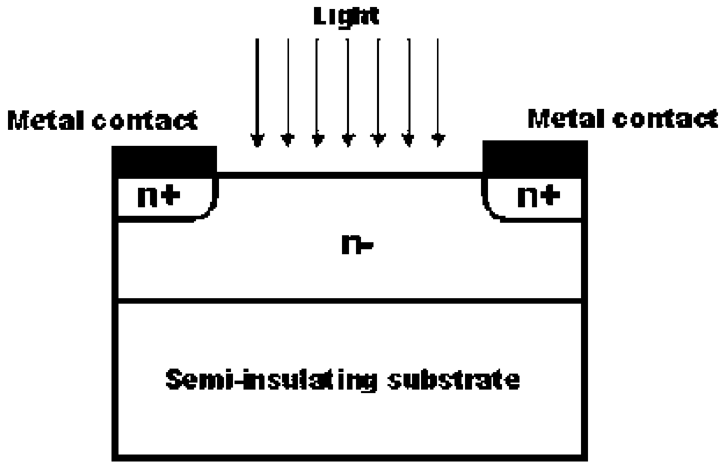
- A light sensitive material such as Cadmium Sulphide (CdS) is deposited on a ceramic substrate.
- Both are enclosed in a metallic container.
- Contact terminals are brought out for an external connection.
- Light is incident on light sensitive material through the glass cap which is added to the top of the assembly.

- The photoconductive materials most frequently used include cadmium sulphide (CdS) and cadmium selenide (CdSe). Both materials respond rather slowly to changes in light intensity.
- The peak spectral response time of CdS units is about 100 ms and 10 ms for CdSe cells. Another important difference between the two materials is their temperature sensitivity.
- There is large change in the resistance of a cadmium selenide cell with changes in ambient temperature, but the resistance of cadmium sulphide remains relatively stable.
- The spectral response of a cadmium sulphide cell closely matches that of the human eye, and the cell is therefore often used in applications where human vision is a factor, such as street light control or automatic iris control for cameras.
- The essential elements of a photoconductive cell are the ceramic substrate, a layer of photoconductive material, metallic electrodes to connect the device into a circuit and a moisture resistant enclosure.



Working:

- When light is incident on a photosensitive material, the following events take place –The incident photons collide with the atoms of the light sensitive material and impart energy to them.
- Due to this energy, the valence electrons will cross the energy band gap and enter the conduction band.
- Thus, the conductivity of the material increases.



- ❖ Resistance is inversely proportional to the intensity of light
- ❖ 'Dark Resistance' is the resistance offered by the LDR in the absence of light
- ❖ The value of resistance depends on the memory effect or the light history effect.

Advantages:

- ❖ Simple construction
- ❖ Easy operation
- ❖ Low cost
- ❖ Good sensitivity
- ❖ Linear response

Disadvantages:

- ❖ Light history effect (resistance changes slowly)
- ❖ Slow response of the device
- ❖ Small range
- ❖ Resistance changes with temperature
- ❖ Poor stability

Applications of LDR:

- ❖ **Object Counter**

  By using a light source and LDR detector, it is possible to count no. of objects passing on a conveyor belt.

- ❖ **Street Light On/Off System**

  LDR can be used in automatic On/Off switch circuit used for street lights. During the day time, the intensity of light falling on LDR is high and therefore low resistance is acquired. Voltage across it is not turn on the transistor. The lamp will remain unenergized and it will continue to remain in OFF state. In the evening, light intensity reduces. Resistance also increases. Therefore, voltage will be enough to turn on the transistor. The relay will be energized and lamp will be in ON state.

2. Explain the construction, characteristics and application of photovoltaic cell. (May 2019)

- A solar cell (also known as a photovoltaic cell or PV cell) is defined as an electrical device that converts light energy into electrical energy through the photovoltaic effect.
- A solar cell is basically a p-n junction diode. Solar cells are a form of photoelectric cell, defined as a device whose electrical characteristics – such as current, voltage, or resistance – vary when exposed to light.
- Individual solar cells can be combined to form modules commonly known as solar panels. The common single junction silicon solar cell can produce a maximum open-circuit voltage of approximately 0.5 to 0.6 volts.
- When combined into a large solar panel, considerable amounts of renewable energy can be generated.

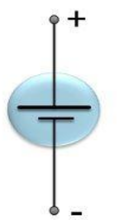
Principle:

The working principle of the device is based on the **photovoltaic effect.**

- A photovoltaic effect is a combination of a physical and chemical process that generates a potential difference when the device is exposed to radiation. This generated voltage corresponds to the intensity of incident radiation.

Symbol of Photovoltaic Cell

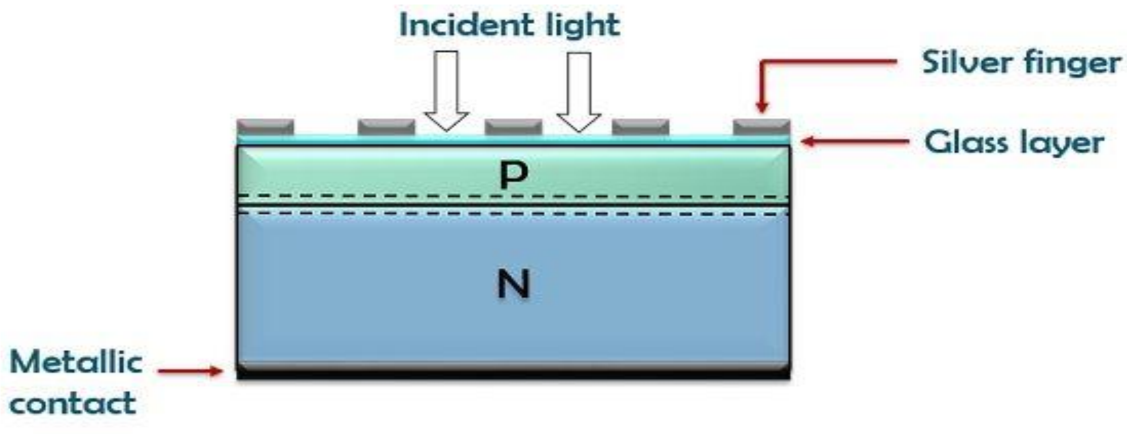
The symbolic representation of a photovoltaic cell is given below:



Symbol of Photovoltaic Cell

Construction of Photovoltaic cell

- The photovoltaic cell is a semiconductor pn junction device. However, its construction is not the same as a normal junction diode.
- It is formed by a combination of p-type semiconductor material with an n-type semiconductor.
- Usually, silicon and selenium are used as the basic semiconductor material. However, gallium arsenide, cadmium sulphide are also majorly used.
- These electrodes do not obstruct light to reach the thin p-type layer. Just below the p-type layer there is a p-n junction.
- We also provide a current collecting electrode at the bottom of the n-type layer. We encapsulate the entire assembly by thin glass to protect the solar cell from any mechanical shock.

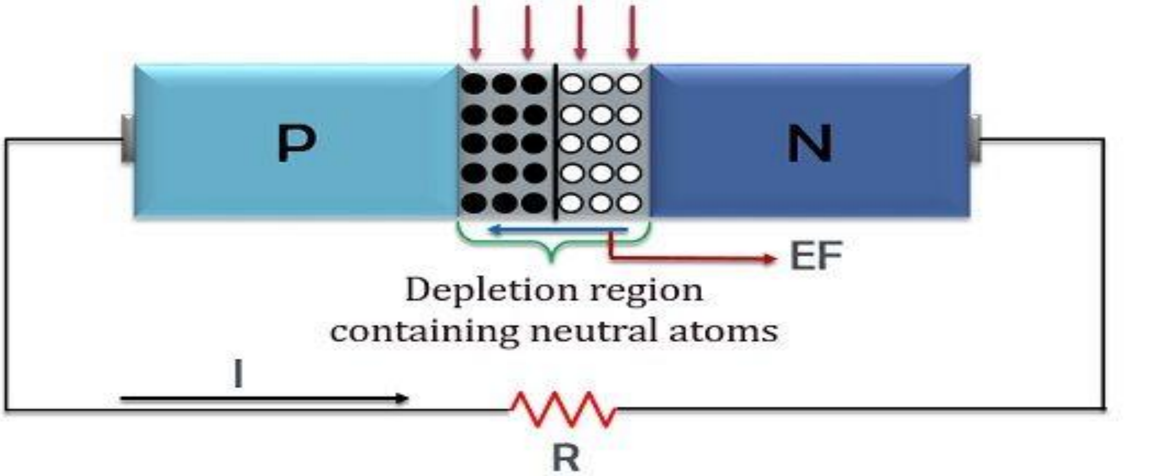


Structure of Photovoltaic Cell

- Here, the above figure clearly represents that the top layer of the device i.e., p region is made very thin in comparison to n region.
- The reason why we have constructed the two regions differently is that the region from where the light ray is allowed to incident must be thin. So, that the incident radiation can easily penetrate to the depletion region (pn junction).
- A layer of glass is placed at the top surface of the device in order to gather maximum incident radiation. Also, metallic fingers are provided at the top surface of the structure.
- Here, we have used silver fingers. As they are good conductors and absorbs the released electrons easily in order to provide proper conduction.

Working of Photovoltaic cell

- ❖ As we have already discussed at the beginning of the article that photovoltaic cells or solar cells are light sensitive devices that produce an electric voltage or current when its surface is illuminated with radiation.
- ❖ So, now have a look at how potential difference is generated when no external potential is provided but a light ray is incident on it.
- ❖ When no any light energy is provided to the device then the device does not conduct. Only the intensity of radiation falling at the surface allows a proportional current to flow through the device.
- ❖ When a light ray is permitted to incident at the top surface of the structure. Then the glass placed gathers the light energy and permit it to reach the p region.
- ❖ As at the time of construction we have discussed that the thin p region is fabricated in order to have easy light penetration towards the junction region.



PN junction Photovoltaic Cell with Resistive Load

Electronics Desk

- ❖ We know that junction is depletion region composed of neutral atoms. Thus, when a light ray incident at the junction then it produces electron-hole pairs. Due to the presence of depletion region an electric field exists.
- ❖ Under the influence of the electric field, electrons move to the N side and holes drift towards the P side.
- ❖ In this way, the movement of charge carriers generates an electric current through the device.

- However, it is to be noted here that the material is a semiconductor. Hence, it does not permit easy flow of charge carriers. So, to have a sufficient amount of current flow to take place metallic fingers are fabricated at the top surface.
- These metallic fingers are nothing but conducting rods that easily absorbs the emitted electrons. This phenomenon gives rise to a potential difference. The generated emf is known as photo voltage. As the voltage is produced due to light.
- It is to be noted here that the energy of the incident radiation (or photon energy) must be greater than the energy band gap between valence and conduction band. This is so because in order to have proper conduction electron must be free to get excited to the conduction band.
- In this way, an electric potential is generated by a photovoltaic cell without using external bias. It generates voltage nearly from 0.5 to 0.6V.
- If we want to increase the overall output through the device, then multiple photocells can be parallely connected.

Advantages of Photovoltaic Cell

- These devices have a long life span as they are highly durable.
- It only requires excitation through light energy.

Disadvantages of Photovoltaic Cell

- It is expensive.
- The presence of light source is necessary.
- As it generates low output thus for high scale production large solar cells are required.

Applications of Photovoltaic Cell

- Solar cells are widely used in space satellites systems.
- These also find its applications in light meters and solar power charging devices as it efficiently utilizes solar energy.

3. What are piezoelectric transducers? Brief about it working and applications in biomedical with different modes of operation. (Sep 2020, May 2019, Nov 2018, May 2018, Nov 2017, Nov 2016, May 2016)

Piezoelectric transducer is an electrical transducer which can convert any form of physical quantity into an electrical signal, which can be used for measurement. An electrical transducer which uses properties of piezoelectric materials for conversion of physical quantities into electrical signals is known as a piezoelectric transducer.

Principle:

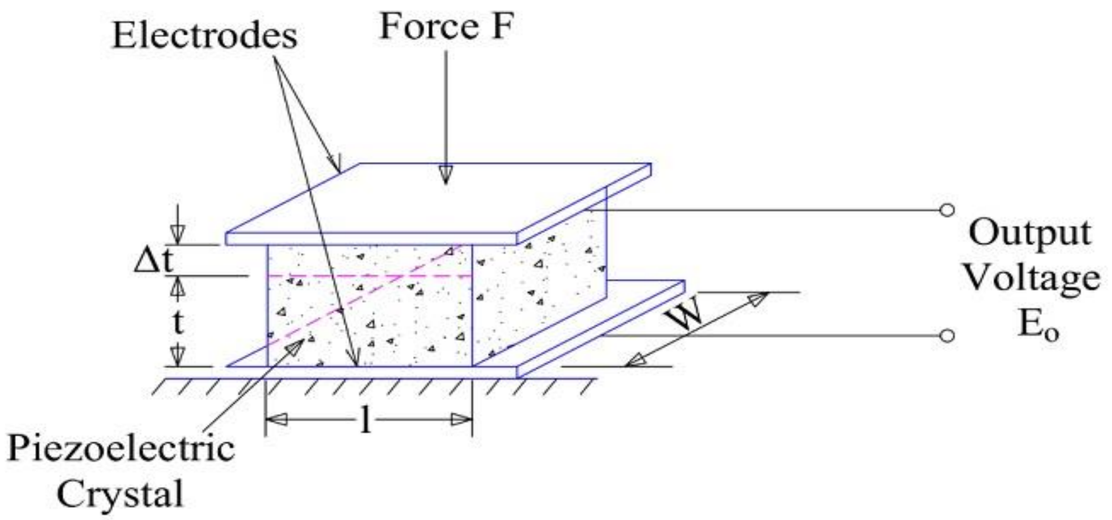
- It is based on the principle of piezoelectric effect.

Piezoelectric Effect

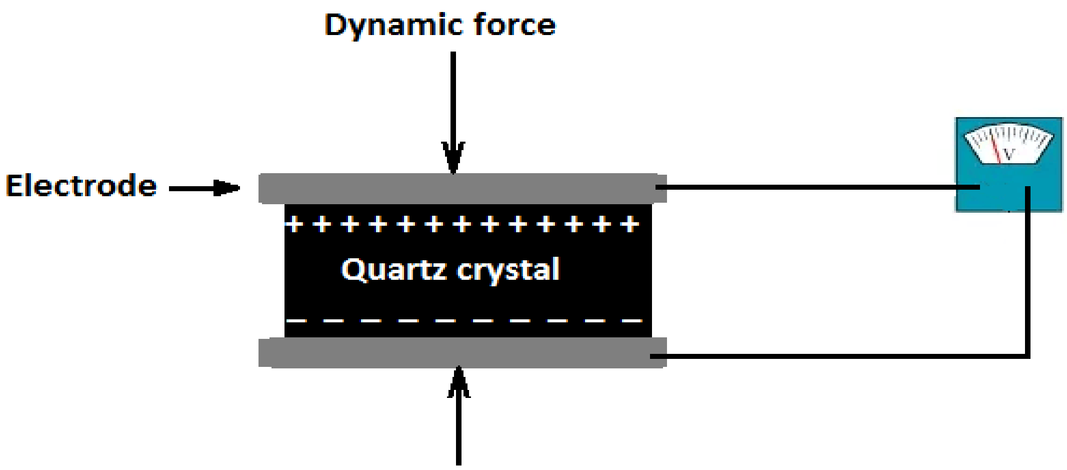
- The EMF develops because of the displacement of the charges. The effect is changeable, i.e. if the varying potential applies to a piezoelectric transducer, it will change the dimension of the material or deform it. This effect is known as the piezoelectric effect.
- The pressure is applied to the crystals with the help of the force summing devices for examples the stress is applied through mechanical pressure gauges and pressure sensors, etc. The deformation induces the EMF which determines the value of applied pressure.

Construction:

- In a piezoelectric transducer, a piezoelectric crystal is sandwiched between the two electrodes.
- When a mechanical deformation takes place, it generates charge and hence it acts as a capacitor.



- A voltage is developed across the electrodes of the transducer which can be measured and calibrated with the deforming force to directly measure the mechanical deforming force.
- It should be noted that, piezoelectric effect is direction sensitive. This means that, the polarity of charge will not be same for a tensile and compressive force.
- The polarity of voltage induced due to a tensile force will be opposite to the polarity of voltage produced due to a compressive force.
- A quartz crystal exhibits a very important property known as the piezoelectric effect.
- When some mechanical pressure is applied across faces of a quartz crystal, a voltage proportional to the applied mechanical pressure appears across the crystal.
- Conversely, when a voltage is applied across the crystal surfaces, the crystal is distorted by an amount proportional to the applied voltage.

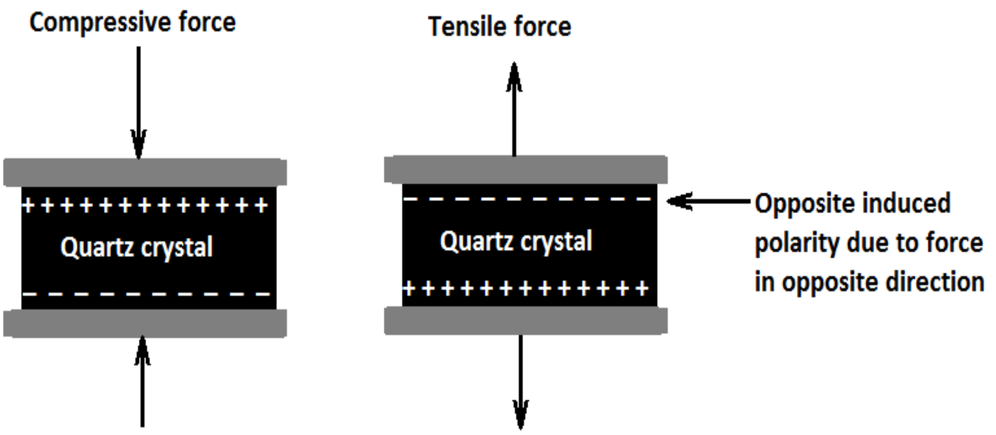


- This phenomenon is known as the piezoelectric effect and the material that exhibits this property is known as a piezoelectric material.
- All piezoelectric transducers work on the piezoelectric effect. In a piezoelectric transducer, a piezoelectric material is used as a sensing element which transforms input mechanical quantity into a proportional electrical signal. This is the basic piezoelectric transducer working principle.
- Besides quartz, the other substances that exhibit the piezoelectric effect are Rochelle salt and tourmaline.

- ❖ Rochelle salt exhibits the greatest piezoelectric effect, but its applications are limited to manufacture of microphones, headsets, and loudspeakers.
- ❖ It is because Rochelle salt is mechanically weakest and strongly affected by moisture and heat. Tourmaline is most rugged but shows least piezoelectric effect.
- ❖ Quartz is a compromise between the piezoelectric effect of Rochelle salt and the mechanical strength of tourmaline. It is inexpensive and readily available in nature.

Piezoelectric Transducer Working

- ❖ In a piezoelectric transducer, a piezoelectric material like quartz crystal is used as a sensing element.
- ❖ When a dynamic force or dynamic pressure is applied to a piezoelectric transducer a charge generates on the surface of the crystal.
- ❖ This charge appears as a potential difference across the electrodes fitted on opposite sides of the crystal.
- ❖ The charge so generated is very small in magnitude. Therefore it has to amplify with the help of a charge amplifier to get a sufficient output. The output instrument is calibrated in terms of input measuring quantity.



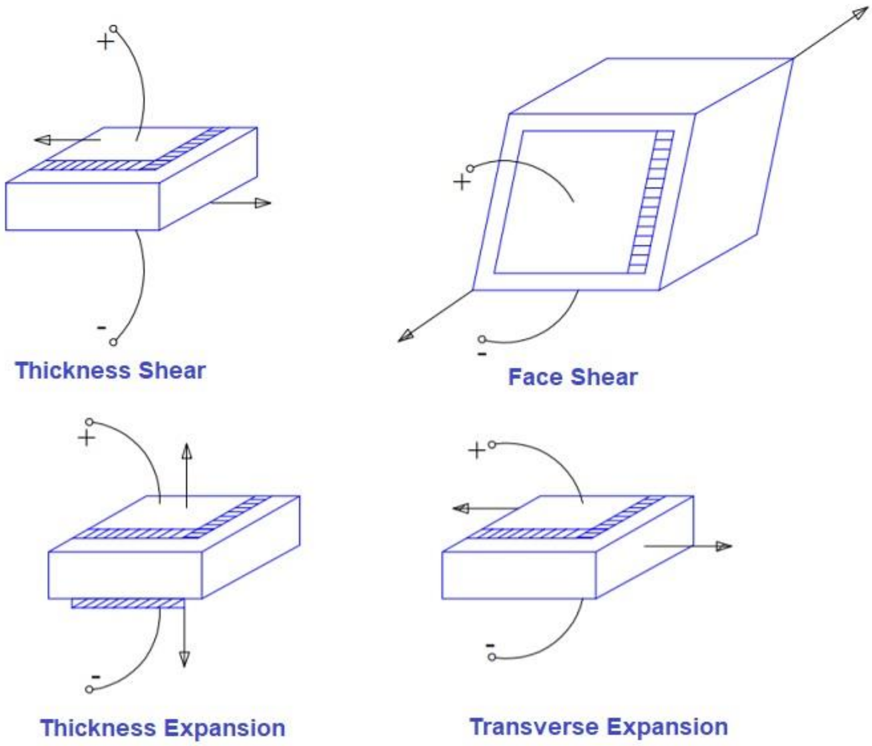
- ❖ If we apply a static force or static pressure, there will be no output voltage. Therefore, input measuring quantity should always be dynamic.
- ❖ The magnitude of the output voltage is directly proportional to the applied force.
- ❖ The polarity of the generated voltage depends upon the direction of the applied force. Therefore, the polarity of generated voltage for tensile force and compressive force will be opposite in polarity on the same piece of piezoelectric material.

Modes of Operation of Piezoelectric Crystal:

Piezoelectric crystal can be used in many modes. There modes are:

- ❖ Thickness shear
- ❖ Face Shear
- ❖ Thickness Expansion
- ❖ Transverse Expansion

These modes are shown in figure below.



Each of the above mode can be converted into electrical signal by using piezoelectric transducer. By cementing two crystals together so that their electrical axes are perpendicular, “Benders” or “Twisters” can be produced. This means that a bending motion applied to a bender produces an output voltage. Similarly, a twisting motion applied to a twister produces a voltage output.

Advantages of Piezoelectric Transducer

- ❖ Piezoelectric crystal transducers have a high-frequency response.
- ❖ They have a high transient response.
- ❖ They are very rugged.

Disadvantages of Piezoelectric Transducer

- The output obtained from the piezoelectric transducers is very low.
- Temperature and humidity may affect the output in some cases.
- They have high impedance.
- They cannot measure static pressure or force. If a static pressure or force is applied to a piezoelectric transducer, the output will be zero.

Applications of Piezoelectric Transducer

- They are very useful for dynamic measurement.
- They are very useful to study a high-speed phenomenon like explosions and blasts.
- They are very useful for stress, force, and pressure measurements.

Applications of Piezoelectric Effect

- **Medical ultrasound applications**: A piezoelectric material can be used for both active and passive transducer applications. In the passive mode the transducer act as a sound receiver i.e. there is the conversion of sound energy into an electrical signal. The converse piezoelectric effect permits a transducer to act as an active sound transmitter.
- In the pulse-echo mode, the transducer is used to perform both the active and passive functions at the same time. A sound wave is propagated into the medium and a faint echo is received back after a small time gap due to the acoustic impedance mismatch between interface materials. This principle is used in transducers for ultrasonic medical imaging applications.

4. Explain about any three spectrophotometric biomedical applications of photoelectric transducers. (Nov 2018, May 2018)

- Spectrophotometry is an analytical method of measuring the amount of visible or ultra-violet light absorbed or transmitted by a substance in solution.
- Concentrations of various substances can also be determined using spectrophotometry and it is a commonly used technique that detects amounts of drugs, proteins and DNA.
- The amount of light absorbed is proportional to the concentration of the solute; it is often then possible to construct a standard curve to figure out unknown concentrations.

- This method has been adopted and used in the study of biochemistry, physics, chemical engineering and more.
- All substances in solution absorb light of one wavelength and transmit light of another wavelength. Absorbance is a characteristic of a substance just like melting point, boiling point, density and solubility.
- There are two types of spectrophotometers. UV-Visible uses light which ranges from 185 to 700 nm and IR spectrophotometers which uses light with a range from 700 to 1500 nm.

Biomedical optics:

- Biomedical optics very well may be the future of our health care industry. Whether you are an athlete, patient, or parent of an infant, biomedical optics will most likely play a significant role in your health care or that of someone you love in the near future.
- Biomedical optics utilize NIR (near-infrared) spectroscopy in a number of ways and provides a safe, non-invasive, and non-destructive method of analysis for a variety of medical needs.
- Biomedical optics offer non-invasive alternatives to many healthcare procedures through the use of spectrophotometric technology.

New medical breakthroughs using NIR spectroscopy

- One of the latest breakthroughs in biomedical optics and spectrophotometric technology involves the monitoring of blood oxygen levels and hemoglobin saturation.
- This area of biomedical optics envelops a large number of applications. For example, spectral technology has revolutionized sports medicine by providing a non-invasive technique for muscle oxygen and hemoglobin saturation monitoring.
- Using NIR spectroscopy, light reflectance and absorption values can easily be measured directly through the skin to obtain accurate blood oxygen and hemoglobin levels.
- This technology is relatively inexpensive and less restrictive than magnetic resonance spectroscopy.
- Instrumentation is designed to be durable, portable, and lightweight, making it a logical option for nearly any clinical sports medicine facility.
- When you consider that NIR light measurements are among the safest methods available, spectroscopy is truly the best option for this application.

- According to U.S. National Library of Medicine National Institutes of Health, “NIRS can objectively evaluate muscle oxidative metabolism in athletes and its modifications following potential therapeutic strategies and specific training programs.”
- Biomedical optics offer non-invasive alternatives to many healthcare procedures through the use of spectrophotometric technology.
- One of the latest and most predominant applications of NIR spectroscopy has been in the neonatal medical care field. NIR spectroscopy provides a non-invasive method that has been proven extremely beneficial for monitoring newborns with critical health conditions.
- The biggest concern for this patient demographic is the risk of potential brain injury, but new advancements in NIR spectroscopy allow for consistent and objective monitoring of brain functioning.
- This form of monitoring is ideal for infants because it does not disrupt other medical needs necessary for the treatment of intensive care newborns.
- NIR spectroscopy can safely and effectively monitor brain functioning of newborns with critical health concerns.

Cutting-edge technology

- At Hunter Lab we are constantly evaluating new innovations in technology and utilizing our knowledge and experience to create products designed specifically to meet industry needs.
- Biomedical optics is sitting on the cutting-edge of medical technology and NIR spectroscopy is shining a light on the future of our health care options.
- New methods and research are constantly underway, and Hunter Lab continually works with researchers and scientists to develop the best instrumentation options for the medical industry.
- Contact Hunter Lab today to learn more about how together we can be leaders in the future of medical technology.

Applications of respiratory mass spectrometry to intensive care

- The mass spectrometer is a quadrupole instrument capable of analyzing up to eight gages simultaneously with a 55.95% response time of 100 milliseconds and an accuracy of f 1 mmHg.

- Stability of the output signals over prolonged periods is achieved by using an automatic sensitivity control which can be applied to any or all the channels.
- This compensates for minor variations in patency of the sampling probes or in gain of the ion current detector, by assuming that the sum of the partial pressures of the gases being analysed remains constant and adjusting the gain on each channel to maintain a constant total.
- This facility has the added advantage of automatically correcting the measured partial pressures for water vapour.
- If the instrument is calibrated with a dry gas mixture at atmospheric pressure, the gains on the channels sensing the individual gases in the mixture will be adjusted automatically to ensure that the sum of these components remains equal to atmospheric pressure, even though the test gas being analysed also contains water vapour.
- This is particularly useful in clinical applications where the degree of humidification varies at different sites in the respiratory circuit.
- The tialve box has twelve inlet ports so that any 12 of the 48 long probes can be included in the monitoring service if required.
- The box is evacuated continuously using a separate vacuum source which decreases the likelihood of gas leaks into the system at this site and maintains a flow through each long probe so that information sampled when the mass spectrometer next dwells on that probe is current.
- The long probes are polyethylene tubing of 1 mm internal diameter and either 15 or 30 m in length.
- Polyethylene was chosen because it is impervious to most gases, absorbs very little water vapour and is cheap and easy to use.
- However, the material is difficult to bond and particular care is required to ensure that a leak-free junction can be established with the patient probe at the bedside terminal panel.
- The validity of information transmitted through tubing of these dimensions has been demonstrated in a study reported recent 1 year.
- The patient probes must be light in weight and unobtrusive. Fine nylon tubing of 0.25.0.38 and 0.5 mm internal diameter and 50 to 300 cm in length has been used.
- The choice is governed by the sampling rate and response time required and this is discussed in greater detail in a subsequent section.

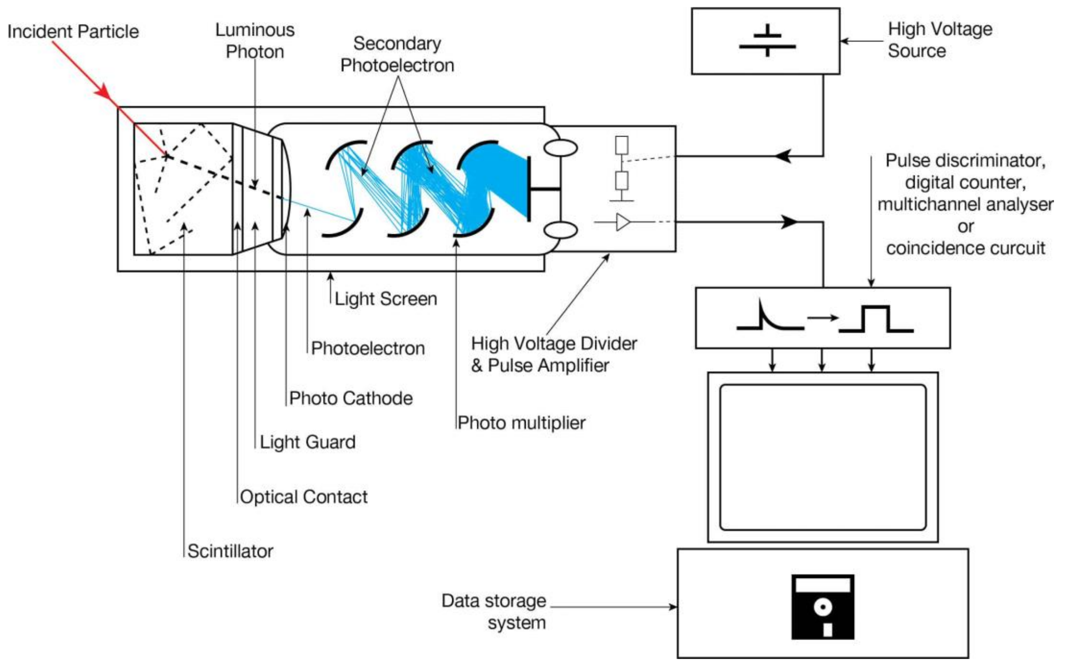
- Another practical point which influences the choice is that tubing of internal diameter 0.38 mm and below acts as a filter which helps to prevent secretions and expired water collecting in the long probes and obstructing a relatively inaccessible part of the system.
- The free end of the patient probe is inserted into the respiratory circuit through a rubber diaphragm without adding to the bulk of the apparatus.
- Display of the data derived with the system is arranged both at the bedside and centrally; digital panel meters have been installed by each bed and an analogue display can be arranged there as well.
- Information from a single bed or a summary relating to all the patients being monitored can be displayed centrally, and data recorded previously can be recalled so that trends occurring during the last hour or last 24 hours can be examined.
- Variables which are usually quoted at BTPS but which are recorded at ATPD because of the operation of the automatic sensitivity control can be corrected to BTPS by the microprocessor before being displayed

5. Explain the construction and working of Photo Multiplier Tube? (Nov 2017)

Photomultiplier tube (PMTs) is a photon detection device that uses the photoelectric effect combined with secondary emission to convert light into an electrical signal.

Construction:

- Photomultiplier tubes (PMTs) are a photon detection device that uses the photoelectric effect combined with secondary emission to convert light into an electrical signal.
- A photomultiplier absorbs light emitted by the scintillator and re-emit it in the form of electrons via the photoelectric effect.
- The PMT has been the main choice for photon detection ever since due to the fact that they have high quantum efficiency and high amplification.
- Photomultiplier tube is a key part of a scintillation detector. In general, a **s**cintillation detector consists of:
    - **Scintillator**: A scintillator generates photons in response to incident radiation.
    - **Photo detector**: A sensitive photo detector (usually a photomultiplier tube (PMT), a charge-coupled device (CCD) camera, or a photodiode), which converts the light to an electrical signal and electronics to process this signal.



Photomultiplier Tube – Principle of Operation

The operation of scintillation counters and photomultiplier tubes is summarized in the following points:

- ❖ Ionization radiation enters the scintillator and interacts with the scintillator material. This cause electrons to be raised to an excited state.
  - ➢ For charged particles the track is the path of the particle itself.
  - ➢ For gamma rays (uncharged), their energy is converted to an energetic electron via either the photoelectric effect, Compton scattering or pair production.
- ❖ The excited atoms of the scintillator material de-excite and rapidly emit a photon in the visible (or near-visible) light range. The quantity is proportional to the energy deposited by the ionizing particle. The material is said to fluoresce.
- ❖ Three classes of phosphors are used:
  - ➢ Inorganic crystals,
  - ➢ Organic crystals,
  - ➢ Plastic phosphors.
- ❖ The light created in the scintillator strikes the photocathode of a photomultiplier tube, releasing at most one photoelectron per photon.

- ❖ Using a voltage potential, this group of primary electrons is electrostatically accelerated and focused so that they strike the first dynode with enough energy to release additional electrons.
- ❖ These secondary electrons are attracted and strike a second dynode releasing more electrons. This process occurs in the photomultiplier tube.
- ❖ Each subsequent dynode impact releases further electrons, and so there is a current amplifying effect at each dynode stage. Each stage is at a higher potential than the previous to provide the accelerating field.
- ❖ Primary signal is multiplied and this amplification continues through 10 to 12 stages.
- ❖ At the final dynode, sufficient electrons are available to produce a pulse of sufficient magnitude for further amplification. This pulse carries information about the energy of the original incident radiation. The number of such pulses per unit time also gives information about the intensity of the radiation.

Advantages of Photomultiplier tube (PMT):

- ❖ Higher responsively in A/W
- ❖ Lower dark current
- ❖ High output S/N ratio
- ❖ Low transport delay
- ❖ Wide spectral response
- ❖ High stability

Disadvantages of Photomultiplier tube (PMT):

- ❖ Shapes and sizes are limited and are physically large.
- ❖ Mechanically fragile (made of glass envelope).
- ❖ Need stable high voltage power supplies.
- ❖ Expensive, available in hundreds of dollars.
- ❖ Responsivity affected by magnetic fields, hence it requires magnetic shielding in critical applications.
- ❖ It requires cooling to LN2 temperatures for noise reduction in critical applications.

Applications:

- ❖ Photomultipliers were the first electric eye devices, being used to measure interruptions in beams of light.

- ❖ Photomultipliers are used in conjunction with scintillators to detect Ionizing radiation by means of hand held and fixed radiation protection instruments, and particle radiation in physics experiments.
- ❖ Photomultipliers are used in research laboratories to measure the intensity and spectrum of light-emitting materials such as compound semiconductors and quantum dots.
- ❖ Photomultipliers are used as the detector in many spectrophotometers. This allows an instrument design that escapes the thermal noise limits on sensitivity, and which can therefore substantially increase the dynamic range of the instrument.
- ❖ Photomultipliers are used in numerous medical equipment designs. For example, blood analysis devices used by clinical medical laboratories, such as flow cytometers, utilize photomultipliers to determine the relative concentration of various components in blood samples, in combination with optical filters and incandescent lamps.
- ❖ An array of photomultipliers is used in a gamma camera. Photomultipliers are typically used as the detectors in flying-spot scanners.

6. Write a note on

a) Photodiode (May 2017)

A photodiode is a semiconductor p-n junction device that converts light into an electrical current. The current is generated when photons are absorbed in the photodiode. Photodiodes may contain optical filters, built-in lenses, and may have large or small surface areas.

Principle:

- ❖ Light energy is converted into electrical energy.Photo current generated is proportional to the absorbed light intensity.

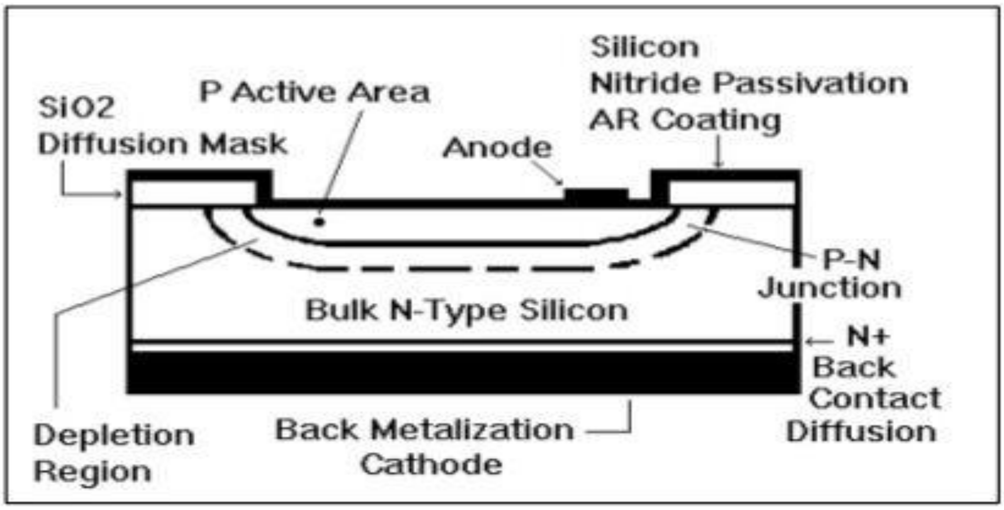
Types of photodiode:

1. **PN photodiode:** The PN photodiode was the first form of photodiode to be developed. Its performance is not as advanced as some of the other types
2. **Avalanche photodiode:** Avalanche photodiode technology is used in areas of low light because of its high levels of gain. Against this it produces high levels of noise. Accordingly this photodiode technology is not suitable for all applications.

3. **Schottky photodiode**: The Schottky photodiode is based upon the Schottky diode. The small diode junction means that there is very little junction capacitance and this means that it can operate at high speeds. As a result, this form of photo diode is often used in high bandwidth optical communication systems, e.g. fibre optic links
4. **PIN photodiode:** The PIN photodiode is one of the most widely used forms of photodiode today. The PIN photodiode collects the light photons more efficiently than the more standard PN photodiode because of the wide intrinsic area between the P and N regions allow for more light to be collected, and in addition to this it also offers a lower capacitance

Construction:

- The photodiodes are available in a metallic package.
- The diode is a p n junction, mounted in an insulated plastic substrate.
- Then we seal the plastic substrate in the metal case.
- On the top of the metal case, there is a transparent window, which allows light to entire up to the PN Junction.
- Two leads, anode and cathode of the diode come out from the bottom of the metal case.
- A tab extending from the side of the bottom portion of the metal case identifies the cathode lead.



Working:

- ❖ An electron will have a negative charge and holes will have a positive charge. The depletion energy will have built in an electric field.
- ❖ Due to that electric field, electron-hole pairs move away from the junction. Hence, holes move to anode and electrons move to the cathode to produce photocurrent.
- ❖ The photon absorption intensity and photon energy are directly proportional to each other. When energy of photos is less, the absorption will be more.
- ❖ This entire process is known as Inner Photoelectric Effect.
- ❖ Intrinsic Excitations and Extrinsic Excitations are the two methods via which the photon excitation happens.
- ❖ The process of intrinsic excitation happens, when an electron in the valence band is excited by photon to conduction band.

Advantages:

- ❖ The photodiode has better frequency response, linearity and spectral response than LDR.
- ❖ Photodiode is suitable in instrument that tests the laser pulse shape.
- ❖ It can operate at high frequencies in the order of 1 MHz.
- ❖ It can be used as variable resistance device.
- ❖ It is highly sensitive to the light.
- ❖ It has lower noise.
- ❖ Fastest photo detector.

Disadvantages:

- ❖ It has rapid increase in dark current with temperature.
- ❖ It has small active area.
- ❖ There is necessity of amplification at low irradiances.
- ❖ It needs offset voltage.

Application:

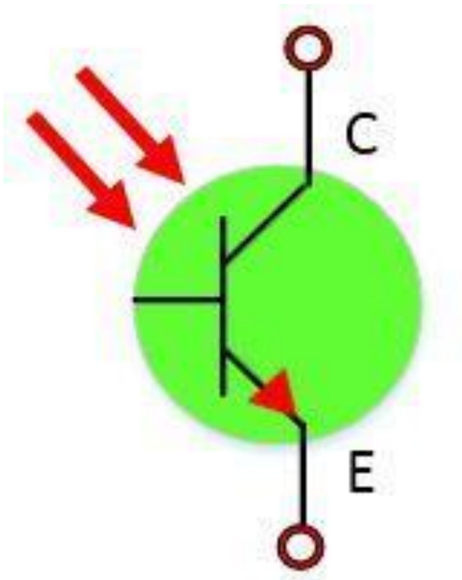
- ❖ Photodiodes are used in solar cell panels.
- ❖ Photodiodes are used in logic circuits.
- ❖ Photodiodes are used in the detection circuits.
- ❖ Photodiodes are used in character recognition circuits.

- ❖ Photodiodes are used for the exact measurement of the intensity of light in science and industry.
- ❖ Photodiodes are faster and more complex than normal PN junction diode and hence are frequently used for lighting regulation and optical communication.

b) Phototransistor (May 2017)

The phototransistor is a semiconductor device that is able to sense light levels and alter the current flowing between emitter and collector according to the level of light it receives.

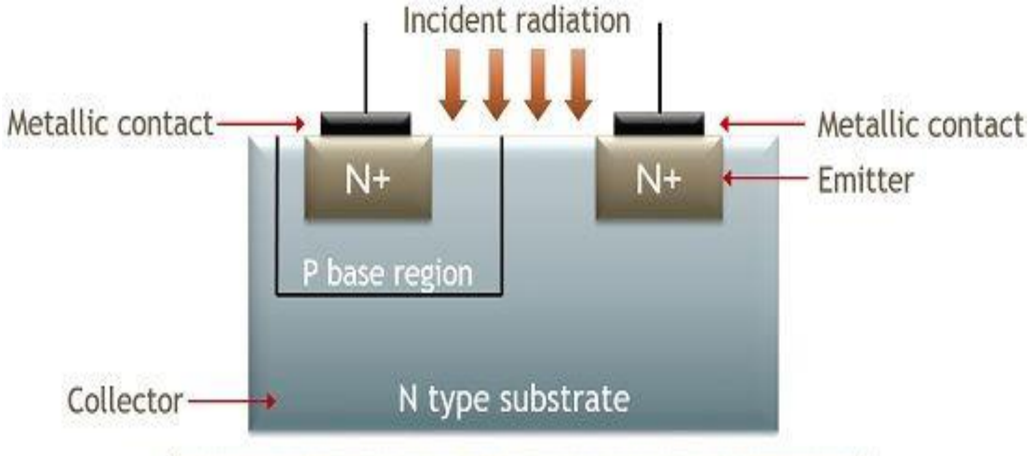
Symbol:



Construction:

- ❖ The light is majorly allowed to incident at the base collector junction.
- ❖ Initially, phototransistors were fabricated from silicon or germanium as their basic material that resultantly provides homojunction structure.
- ❖ However, in recent times, these are constructed using materials likes gallium or arsenide.
- ❖ Thereby, providing a heterojunction structure. This is so because these structures exhibit large conversion efficiency.
- ❖ This implies they are more capable of changing light energy into electrical energy as compared to homo junction transistors.

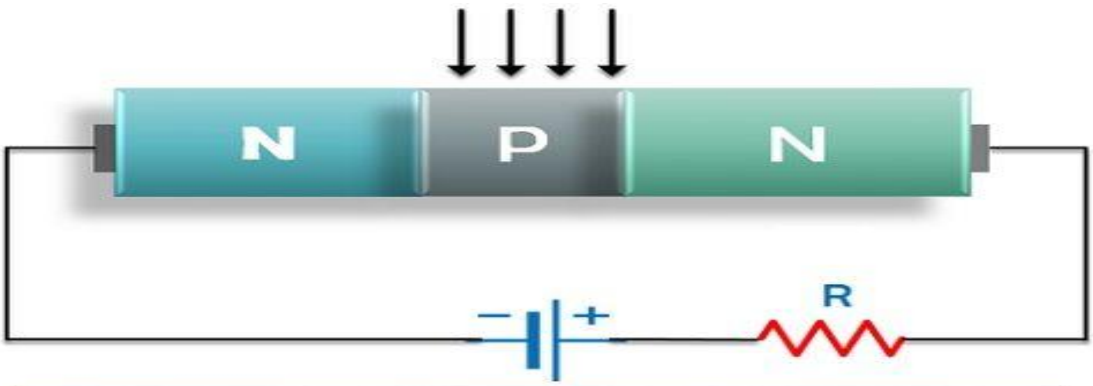
- Phototransistors are mainly enclosed in a metallic case that consists of the lens at the top in order to gather the incident radiation.



Structure of Phototransistor

Working:

- The operation of a phototransistor depends on the intensity of radiation falling at its base region. Its working is almost similar to a normal transistor, however; the variation lies in the input current that drives the circuit. And in the case of a phototransistor, the incident light generates driving current.



Working structure of Phototransistor

- In the circuit arrangement, we can clearly see that the base region is kept unconnected with the external supply voltage and is used as the region for radiation incidence. Only the collector region is connected to the positive side of the supply provided along with emitter which is connected to the negative side. However, the output is taken at the emitter terminal of the transistor.

- ❖ When no any light is allowed to incident at the base region of the transistor, the due to temperature variation, movement of minority carriers across the junction generates a very small current through the transistor which is reverse saturation current basically termed as dark current. Here, the base current IB is majorly 0.
- ❖ Here, in this case, the output current will be less as compared to supply provided. But, when a certain amount of light energy is allowed to fall at the base of the transistor, then electron and hole pair gets generated. The applied electric field causes the electrons to move into the emitter region, thereby generating large electric current.

Advantages:

- ❖ There are numerous applications of phototransistor such as light measurement, light sensitive switch, opto-coupler etc.
- ❖ Phototransistor is more responsive to light than photoresistor.
- ❖ Phototransistors are cheaper.
- ❖ Phototransistors can produce a voltage which can be used in conjunction with microcontroller housing ADC.
- ❖ Output current of phototransistor is easily obtainable.

Disadvantages:

- ❖ Silicon phototransistors do not handle higher voltages above 1000V.
- ❖ They are more susceptible to electricity surges/spikes and EM energy from radiations.
- ❖ It has nonlinear characteristic and it is temperature sensitive.
- ❖ Large dispersion between individual

Application:

- ❖ The phototransistor is widely used in electronics devices likes smoke detectors, infrared receiver, CD players, lasers etc. for sensing light.
- ❖ They also find applications in Opto-isolators, Position sensing, Security systems, Coin counters, etc.

7. Explain in detail about equivalent circuit of photoelectric transducer. (May 2017, Nov 2015)

The photoelectric transducer can be defined as, a transducer which changes the energy from the light to electrical. It can be designed with the semiconductor materials.

Principle:

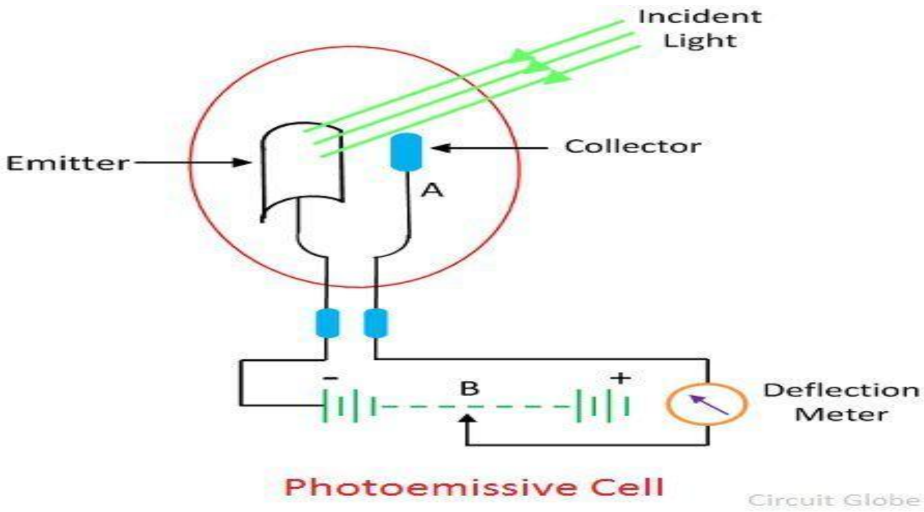
- It is based on the principle of photoelectric effect.

Photoelectric Effect – Electrically charged particles are released from or within a material when it absorbs electromagnetic radiation. The effect is often defined as the ejection of electrons from a metal plate when light falls on it.

Types of photoelectric transducer:

Photo emissive Cell:

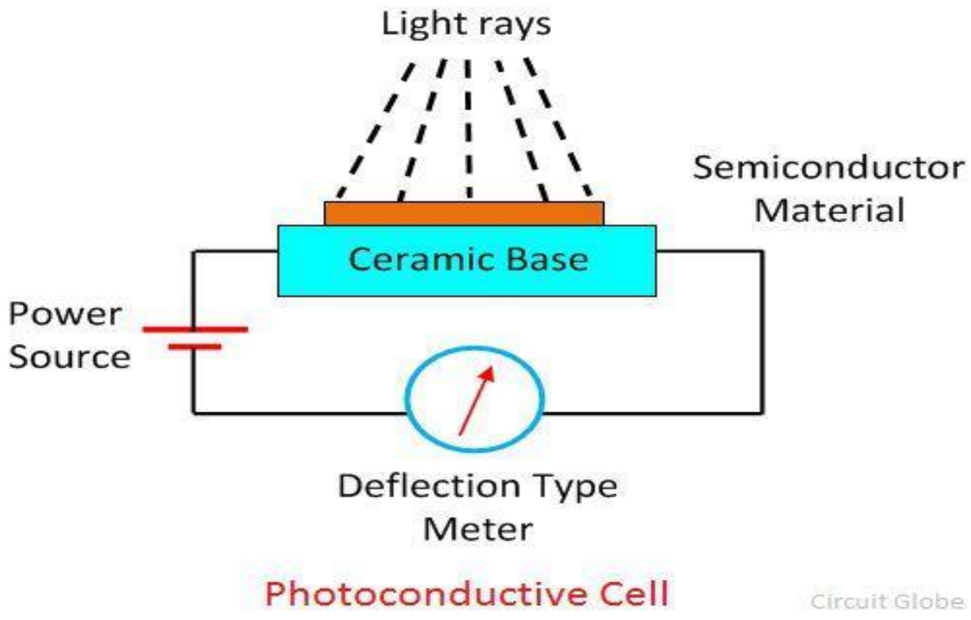
- The Photo emissive cell converts the photons into electric energy. It consists the anode rode and the cathode plate.
- The anode and cathode are coated with a Photo emissive material called caesium antimony.



- When the radiation of light fall on cathode plates the electrons starts flowing from anode to cathode. Both the anode and the cathode are sealed in a closed, opaque evacuated tube.
- When the radiation of light fall on the sealed tube, the electrons starts emitting from the cathode and moves towards the anode.
- The anode is kept to the positive potential. Thus, the photoelectric current starts flowing through the anode.
- The magnitude of the current is directly proportional to the intensity of light passes through it.

<u>Photoconductive cell:</u>

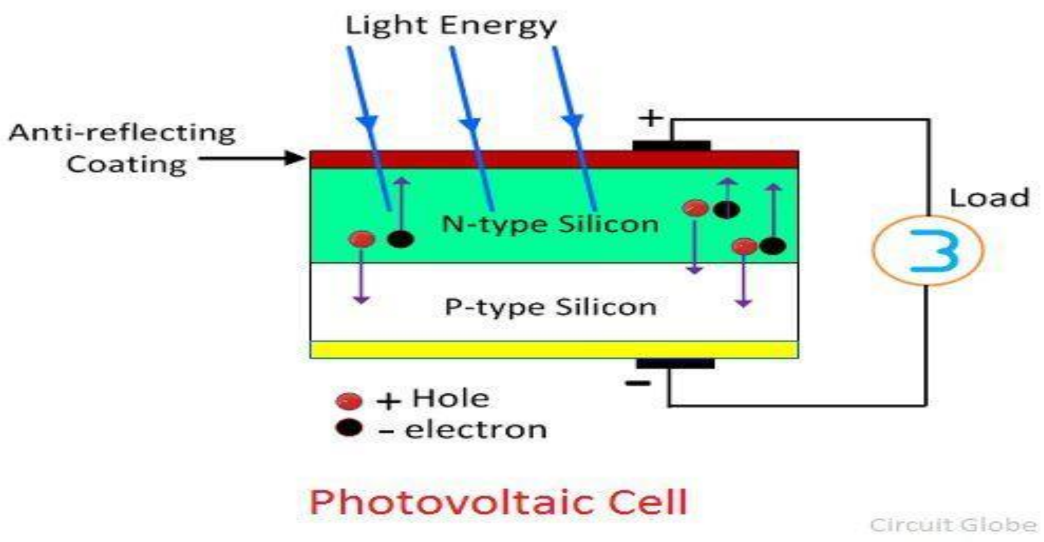
- The photoconductive cell converts the light energy into an electric current. It uses the semiconductor material like cadmium selenide, Ge, Se, as a photo sensing element.



- Photoconductive-cellWhen the beam of light falls on the semiconductor material, their conductivity increases and the material works like a closed switch. The current starts flowing into the material and deflects the pointer of the meter.

<u>Photovoltaic cell:</u>

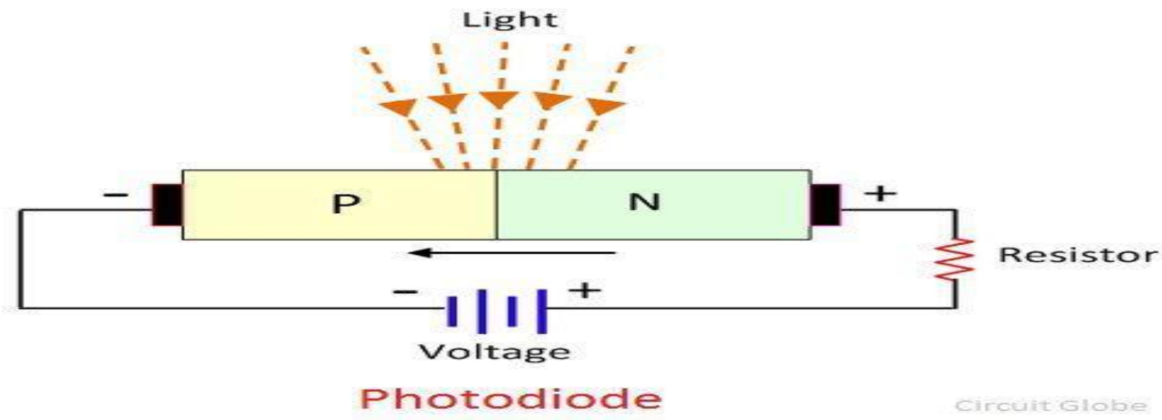
- The photovoltaic cell is the type of active transducer. The current starts flowing into the photovoltaic cell when the load is connected to it.



- The silicon and selenium are used as a semiconductor material. When the semiconductor material absorbs heat, the free electrons of the material starts moving.
- This phenomenon is known as the photovoltaic effect.photo-voltaic-cell
- The movements of electrons develop the current in the cell, and the current is known as the photoelectric current.

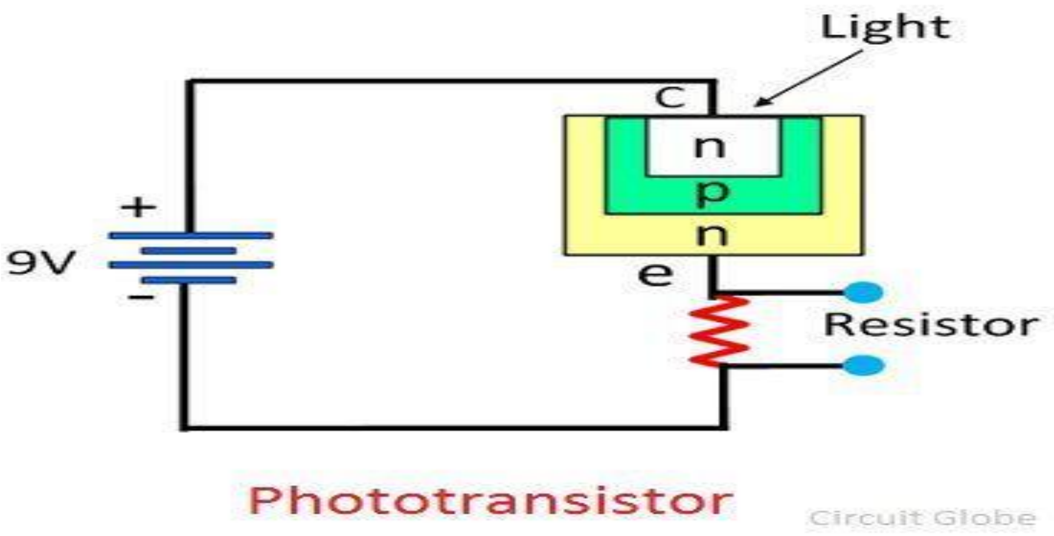
Photodiode:

- The photodiode is a semiconductor material which converts the light into the current. The electrons of the semiconductor material start moving when the photodiode absorbs the light energy. The response time of the photodiode is very less. It is designed for working in reverse bias.



Phototransistor:

- The phototransistor is a device that converts the light energy into electric energy. It produces both the current and voltage.
- The photovoltaic cell is a bipolar device which is made of semiconductor material. The semiconductor material is enclosed in an opaque container in which the light easily reaches to the photosensitive elements.
- The element absorbs light, and the current starts flowing from base to emitter of the device. This current is converted into the voltages.



Advantages:

- It senses all kinds of materials.
- It has longer life.
- It has long sensing range and very reliable.
- It has very fast response time.

Disadvantages:

- Over coarse of time lens get contaminated.
- It's sensing range is affected due to color and reflectivity of the target.
- These beam type requires transmitter (Tx) and receiver (Rx) at two separate locations.

Applications:

- These transducers are used in biomedical applications
- Pickups of pulse
- Pneumograph respiration
- Measure blood pulsatile volume changes
- Records Body movements.

8. (a) Compare the phototube and photomultiplier tube. (Nov 2016)

Phototube	Photomultiplier tube
A phototube, also known as a photoelectric	Photomultiplier is vaccum devices (unless

tube, is a light-sensitive electronic device. It is designed to emit an electric current when exposed to light or another form of electromagnetic radiation. The phototube has earned the moniker "electric eye," because of its use in a wide range of light-sensing applications.	you consider what is called Silicon Photomultiplier), photodiode is usually silicon device (however, there are vaccum “phototubes” too). The word multiplier means it has internal gain, which is usually quite high, therefore it is way more suitable for weak signals, especially short pulses.
The current is dependent on the frequency and intensity of incoming photons.	No amplification takes place, so the current through the device is typically of the order of a few microamperes.
One major application of the phototube was the reading of optical sound tracks for projected films. Phototubes were used in a variety of light-sensing applications until they were superseded by photo resistors and photodiodes.	Photomultipliers are used as the detector in many spectrophotometers. This allows an instrument design that escapes the thermal noise limit on sensitivity, and which can therefore substantially increase the dynamic range of the instrument. Photomultipliers are used in numerous medical equipment designs.

(b) Discuss the application of spectrophotometer in haematological test using Africa diagrams.(Nov 2016)

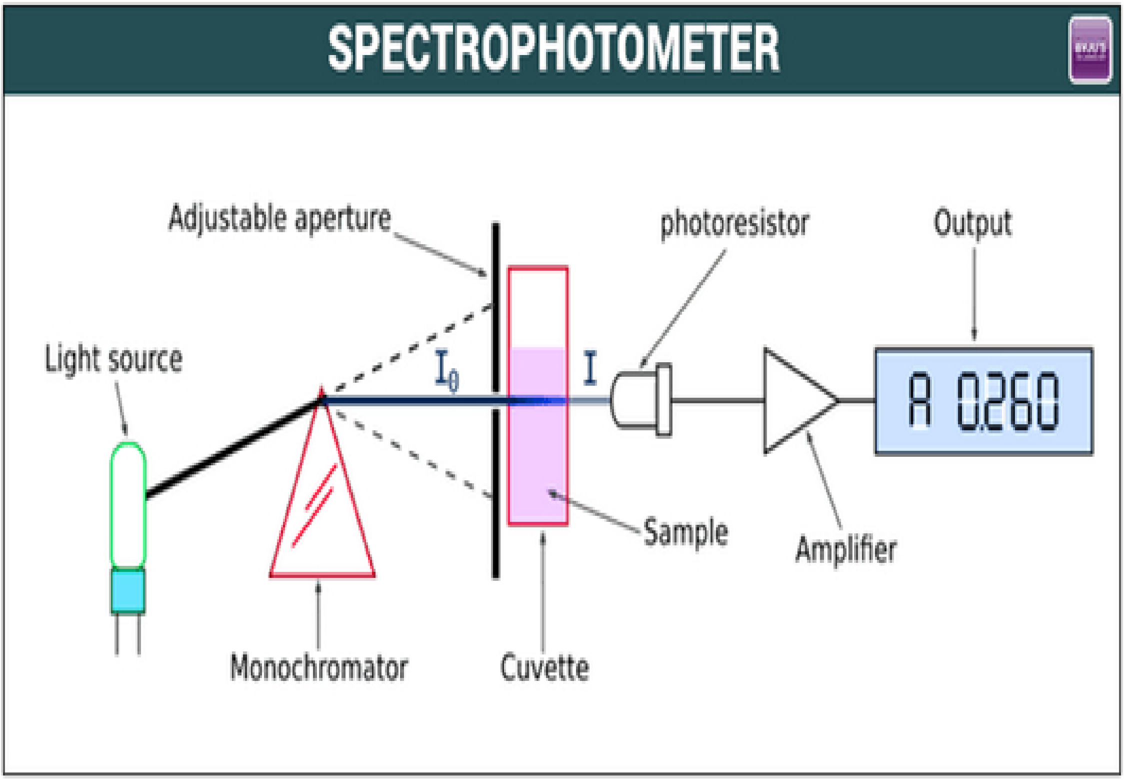
It is an optical instrument that measures the intensity of light in relation to the wavelength. It can measure just about anything such as:

- Plastics
- Paper
- Liquid

- Metal
- Fabric

Principle:

- Spectrophotometer is a refined version of a colorimeter. In other words, it functions the same way as a colorimeter but with added features. A colorimeter uses a filter which enables a broad range of wave lengths to pass through.
- A spectrophotometer a prism or grating is used for the incident beam to split into different wavelengths. The waves of the particular wavelengths can be adjusted to fall on the test solution



Applications:

- It is useful in qualitative analysis, especially when identifying classes of compounds in both biological and pure state.
- The spectrophotometer is essential in quantitative analysis of biochemistry practical such as in determining the unknown concentration of a given species through absorption spectrometry. A perfect example is the nucleic acid in a protein.
- Enzyme assay is the primary use of spectrophotometry.

- Identifying the molecular weight of a particular sample such as amine picrates, ketone compounds, aldehyde, and sugar, to name a few.

Other primary applications of spectrophotometer include the following:

- Identifying impurities.
- Detecting the concentration of substances.
- Organic compounds' structure elucidation.
- Identifying the characteristics of a protein.
- Identifying the dissolved oxygen content in a body of water.
- Analysis of respiratory gas in hospitals.
- Functional group detection.
- Determining molecular weight in a particular compound.
- Identifying classes of compounds.

9. Explain in detail the electrical equivalent circuit for Piezo electric ultrasound transducer. (May 2015)

- Ultrasonic transducers and ultrasonic sensors are devices that generate or sense ultrasound energy. They can be divided into three broad categories: transmitters, receivers and transceivers.
- Transmitters convert electrical signals into ultrasound, receivers convert ultrasound into electrical signals, and transceivers can both transmit and receive ultrasound.

Principle:

An electric current passes through a cable to the transducer and is applied to the crystals, causing them to deform and vibrate. This vibration produces the ultrasound beam. The frequency of the ultrasound waves produced is predetermined by the crystals in the transducer.

Construction:

- For taking an ultrasound imaging, we need a transducer probe, transducer pulse control, cpu, display, keyboard, disk storage device, printer.
- The transducer probe is used for sending and receiving the sound waves.
- The transducer consist of a piezoelectric crystal which generates and detects ultrasonic pulses.

- The piezoelectric materials generally used are barium titanate and lead ziorconatetitanate.
- The probes are designed to achieve the highest sensitivity and penetration, optinum focal characteristics and the best possible resolution. this requires that the acoustic energy the transmitted efficiently into the patient
- Transducer pulse control: changes the amplitude, frequency, duration of the pulse emitted from the transducer probe
- CPU: computer that does all the calculation and contain the electrical power supply for itself and the transducer probe
- Display: display the image
- Keyboard: Inputs the data and take measurements from the display
- Printer: Print the image

Working:

- Ultrasound waves are produced by a transducer, which can both emit ultrasound waves, as well as detect the ultrasound echoes reflected back. In most cases, the active elements in ultrasound transducers are made of special ceramic crystal materials called piezoelectrics.
- These materials are able to produce sound waves when an electric field is applied to them, but can also work in reverse, producing an electric field when a sound wave hits them.
- When used in an ultrasound scanner, the transducer sends out a beam of sound waves into the body.
- The sound waves are reflected back to the transducer by boundaries between tissues in the path of the beam (e.g. the boundary between fluid and soft tissue or tissue and bone).
- When these echoes hit the transducer, they generate electrical signals that are sent to the ultrasound scanner.
- Using the speed of sound and the time of each echo’s return, the scanner calculates the distance from the transducer to the tissue boundary. These distances are then used to generate two-dimensional images of tissues and organs.
- Image of an ultrasound transducerAn ultrasound transducer.
- During an ultrasound exam, the technician will apply a gel to the skin.

- ❖ This keeps air pockets from forming between the transducer and the skin, which can block ultrasound waves from passing into the body.

Advantages:

- ❖ Not affected by color or transparency of objects.
- ❖ Can be used in dark environments.
- ❖ Low-cost option.
- ❖ Not highly affected by dust, dirt, or high-moisture environments.
- ❖ Cannot work in a vacuum.
- ❖ Not designed for underwater use.
- ❖ Sensing accuracy affected by soft materials.

Disadvantages:

- ❖ Some common disadvantages are limited testing distance, inaccurate readings, and inflexible scanning methods. All of these drawbacks, however, can be mitigated and even overcome with the right NDT tools and techniques.

Applications:

- ❖ It is used for the imaging of internal body structures such as muscles, joints and internal organs.
- ❖ Ultrasonic images are known as sonograms. In this process, pulses of ultrasound are sent to the tissue using a probe.

10. With a suitable diagram explain the construction and working of spectrophotometer with biomedical application. (Nov 2015)

- ❖ A spectrophotometer is an instrument that measures the amount of light absorbed by a sample.
- ❖ Spectrophotometer techniques are mostly used to measure the concentration of solutes in solution by measuring the amount of the light that is absorbed by the solution in a cuvette placed in the spectrophotometer.
- ❖ It is an optical instrument that measures the intensity of light in relation to the wavelength. It can measure just about anything such as: Plastics,Paper, liquid,Metal, Fabric

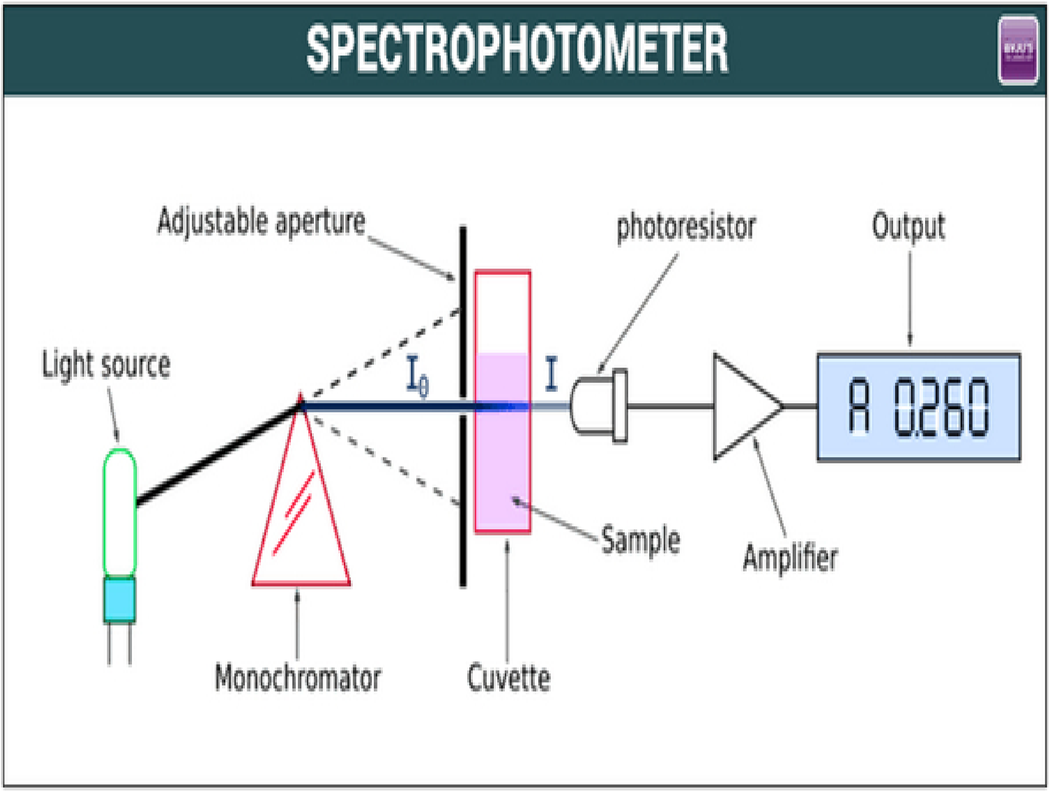
Principle:

- Spectrophotometer is a refined version of a colorimeter. In other words, it functions the same way as a colorimeter but with added features. A colorimeter uses a filter which enables a broad range of wave lengths to pass through.
- A spectrophotometer a prism or grating is used for the incident beam to split into different wavelengths. The waves of the particular wavelengths can be adjusted to fall on the test solution

PARTS OF SPECTROPHOTOMETER:

There are 7 essential parts of a spectrophotometer

- Light source – In spectrophotometer three different sources of light are commonly used to produce light of different wavelength. The most common source of light used in the spectrophotometer for the visible spectrum is a tungsten lamp. For Ultraviolet radiation, commonly used sources of are the hydrogen lamp and the deuterium lamp. Nernst filament or globar is the most satisfactory sources of IR (Infrared) radiation.
- Monochromator – To select the particular wavelength, prism or diffraction grating is used to split the light from the light source.
- Sample holder – Test tube or Cuvettes are used to hold the colored solutions. They are made up of glass at a visible wavelength.
- Beam splitter – It is present only in double beam spectrophotometer. It is used to split the single beam of light coming from the light source into two beams.
- Mirror – It is also present only and double beam spectrophotometer. It is used to the right direction to the splitted light from the beam splitter.
- Photodetector system – When light falls on the detector system, an electric current is generated that reflects the galvanometer reading.
- Measuring device – The current from the detector is fed to the measuring device – the galvanometer. The meter reading is directly proportional to the intensity of light.



Working:

- When using a Spectrophotometer, it requires being calibrated first which is done by using the standard solutions of the known concentration of the solute that has to be determined in the test solution.
- For this, the standard solutions are filled in the Cuvettes and placed in the Cuvette holder in the spectrophotometer that is similar to the colorimeter.
- There is a ray of light with a certain wavelength that is specific for the assay is directed towards the solution. Before reaching the solution the ray of light passes through a series of the diffraction grating, prism, and mirrors.
- These mirrors are used for navigation of the light in the spectrophotometer and the prism splits the beam of light into different wavelength and the diffraction grating allows the required wavelength to pass through it and reaches the Cuvette containing the standard or Test solutions.
- It analyzes the reflected light and compares with a predetermined standard solution.
- When the monochromatic light (light of one wavelength) reaches the Cuvette some of the light is reflected, some part of the light is absorbed by the solution and the

remaining part is transmitted through the solution which falls on the photodetector system.

- ❖ The photodetector system measures the intensity of transmitted light and converts it into the electrical signals that are sent to the galvanometer.
- ❖ The galvanometer measures the electrical signals and displays it in the digital form. That digital representation of the electrical signals is the absorbance or optical density of the solution analyzed.
- ❖ If the absorption of the solution is higher than there will be more light absorbed by the solution and if the absorption of the solution is low then more lights will be transmitted through the solution which affects the galvanometer reading and corresponds to the concentration of the solute in the solution.
- ❖ By putting all the values in the formula given in the below section one can easily determine the concentration of the solution.
- ❖ In double beam spectrophotometers, the beam splitters are present which splits the monochromatic light into two beams one for the standard solution and the other for test solution.
- ❖ In this, the absorbance of Standard and the Test solution can be measured at the same time and any no. of test solutions can be analyzed against one standard.
- ❖ It gives more accurate and precise results, eliminates the errors which occur due to the fluctuations in the light output and the sensitivity of the detector

Advantages:

- ❖ The single beam design are low cost, high throughput, and hence high Sensitivity , because the optical system is simple.

Disadvantages:

- ❖ An appreciable amount of Time elapses between taking the reference (I) and Making the sample measurement (Io) so that there can be problems with drift.

Applications:

- ❖ It is useful in qualitative analysis, especially when identifying classes of compounds in both biological and pure state.

- The spectrophotometer is essential in quantitative analysis of biochemistry practical such as in determining the unknown concentration of a given species through absorption spectrometry. A perfect example is the nucleic acid in a protein.
- Enzyme assay is the primary use of spectrophotometry.
- Identifying the molecular weight of a particular sample such as amine picrates, ketone compounds, aldehyde, and sugar, to name a few.

Other primary applications of spectrophotometer include the following:

- Identifying impurities.
- Detecting the concentration of substances.
- Organic compounds’ structure elucidation.
- Identifying the characteristics of a protein.
- Identifying the dissolved oxygen content in a body of water.
- Analysis of respiratory gas in hospitals.
- Functional group detection.
- Determining molecular weight in a particular compound.
- Identifying classes of compound.

BM T46 – BIOMEDICAL SENSORS AND TRANSDUCERS

UNIT-4

2 MARKS

1. **Mention the different types of electrodes used in biomedical field. (Sep 2020)**

There are three main types of electrodes used in biomedical field

- ❖ Microelectrodes.
- ❖ Depth and Needle electrodes
- ❖ Body Surface electrodes

2. **What are polarizable and non polarizable electrodes? (Sep 2020)**

- ❖ A polarizable electrode is an electrode in an electrochemical cell that is characterized by charge separation at the electrode-electrolyte boundary.
- ❖ A non-polarizable electrode is an electrode in an electrochemical cell that can be characterized by no charge separation at the electrode-electrolyte boundary.

3. **What are the reasons for artifacts? (May 2019)**

Artifacts include tools, clothing, and decorations made by people. They provide essential clues for researchers studying ancient cultures material remains of a culture, such as tools, clothing, or food to expose by digging.

4. **Mention the need of an electrode gel. (May 2019, May 2015)**

Electrolyte gel is designed to provide carbohydrate for fast energy and key electrolytes for hydration. GO Energy + Electrolyte gels are particularly effective when exercising in hot conditions causing sweat rates to be high. Available in Lemon & Mint, Salted Caramel or Raspberry flavours, for a fresh or fruity taste.

5. **Define half cell potential. (Nov 2018, May 2018)**

Half-cell potential refers to the potential developed at the electrode of each half cell in an electrochemical cell. In an electrochemical cell, the overall potential is the total potential calculated from the potentials of two half cells.

6. **What are perfectly polarizable electrodes? Give an example. (Nov 2018, May 2018)**

Electrodes in which no actual charges cross the electrode-electrolyte interface when current is applied.

E.g. Platinum electrode

7. **What are motion artifacts. (Nov 2017, May 2016)**

Motion artifact is a patient-based artifact that occurs with voluntary or involuntary patient movement during image acquisition. Misregistration artifacts, which appear as blurring, streaking, or shading, are caused by patient movement during a CT scan.

8. **What are the types of surface electrodes. (Nov 2017, May 2015)**

There are five types of surface electrodes

- ❖ Metal Plate electrodes
- ❖ Suction cup electrodes
- ❖ Adhesive tape electrodes
- ❖ Multi point electrodes
- ❖ Floating electrodes.

9. **Define polarization. (May 2017)**

Polarization is the change of potential from a stabilized state, e.g. from the open-circuit electrode potential as the result of the passage of current. Polarization is sometimes also referred to as "over voltage" or "over potential".

10. **List out the biomedical applications of silver chloride electrodes. (May 2017)**

Silver chloride electrodes are also used by many applications of biological electrode systems such as bio monitoring sensors as part of

- ❖ Electrocardiography (ECG)
- ❖ Electroencephalography (EEG)
- ❖ Transcutaneous electrical nerve stimulation (TENS) to deliver current.

11. **Write down the method of insertion in needle electrode. (Nov 2016)**

The Needle Electrode insertion site is on the inner leg, approximately 3 finger widths (2”) away from the center of the ankle and one finger width towards the back of the leg. Place 3 fingers on the center of the ankle bone. Move the top finger one finger width towards the back of the leg.

12. **Define microelectrodes. (Nov 2016)**

A microelectrode is an electrode used in electrophysiology either for recording neural signals or for the electrical stimulation of nervous tissue.

13. List the electrodes used in ECG and EEG. (May 2016)

ECG

- ❖ Flat paper thin sticker electrode
- ❖ Self-adhesive circular pad electrode

EEG

- ❖ Traditional Wet Ag/AgCl Electrodes
- ❖ Active Dry Single Gold Pin-Based Electrodes
- ❖ Hybrid Dry Multiple Spikes-Based Electrodes
- ❖ Passive Dry Solid-Gel Based Electrodes

14. Write a note on Einthoven triangle. (Nov 2015)

Einthoven's triangle is an imaginary formation of three limb leads in a triangle used in electrocardiography, formed by the two shoulders and the pubis. The shape forms an inverted equilateral triangle with the heart at the center. It is named after Willem Einthoven, who theorized its existence.

15. Define electrical double layer. (Nov 2015)

A double layer (DL, also called an electrical double layer, EDL) is a structure that appears on the surface of an object when it is exposed to a fluid. The object might be a solid particle, a gas bubble, a liquid droplet, or a porous body.

11 MARKS

1. Mention the electrodes used in biomedical application and explain the various electrodes with neat sketch. (Sep 2020, May 2019, Nov 2018, May 2018, Nov 2017, Nov 2016, May 2016, May 2015, Nov 2015)

There are three main types of electrodes:

- ❖ Microelectrodes.
- ❖ Depth and Needle electrodes.
- ❖ Surface electrodes.

Microelectrodes:

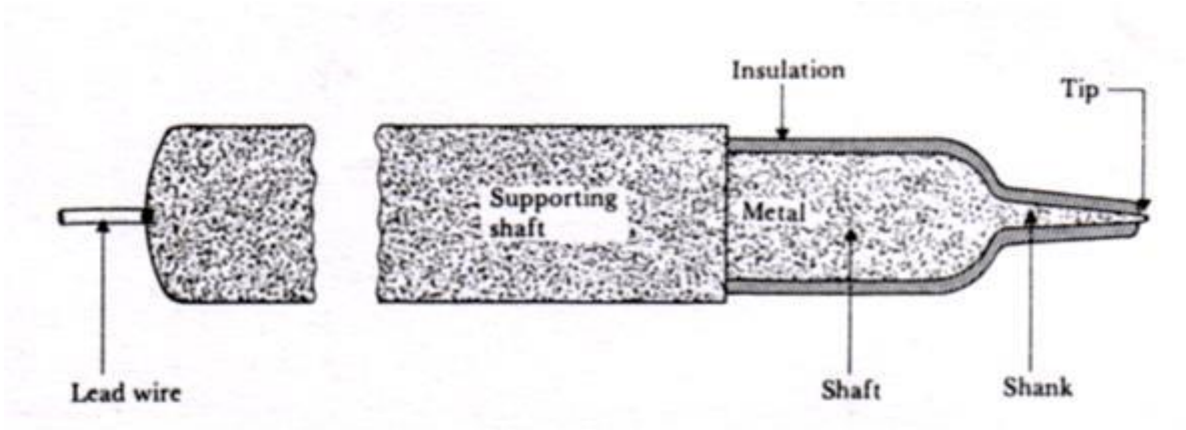
A microelectrode is an electrode which is used to measure bio electric potential near or within the cell.

There are two types of microelectrodes

- ❖ Metallic microelectrode
- ❖ Non-Metallic microelectrode

Metallic microelectrode:

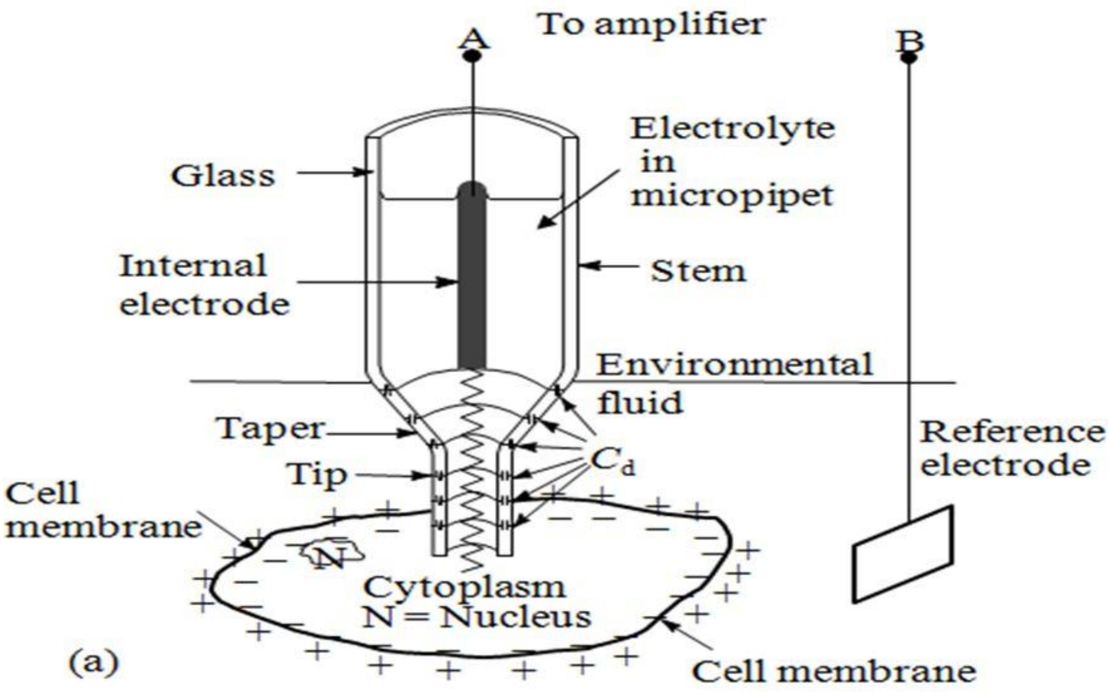
- ❖ Metal Microelectrodes are made up of fine tungsten or stainless steel of 0.5 to 5 microns cross section.
- ❖ They are made by electrolytic itching.
- ❖ They are coated almost up to the tip by insulating material.
- ❖ To reduce impedance, micro tip is chloride.



Non-Metallic microelectrode:

- ❖ It consists of glass micropipette of diameter 1 micrometer.
- ❖ Micropipette filled with electrolyte solution that is compatible with cellular fluids is used.
- ❖ Stem of Micropipette has a thin flexible wire made out of chloride silver, stainless steel or tungsten.

MICROPIPET



Depth electrode:

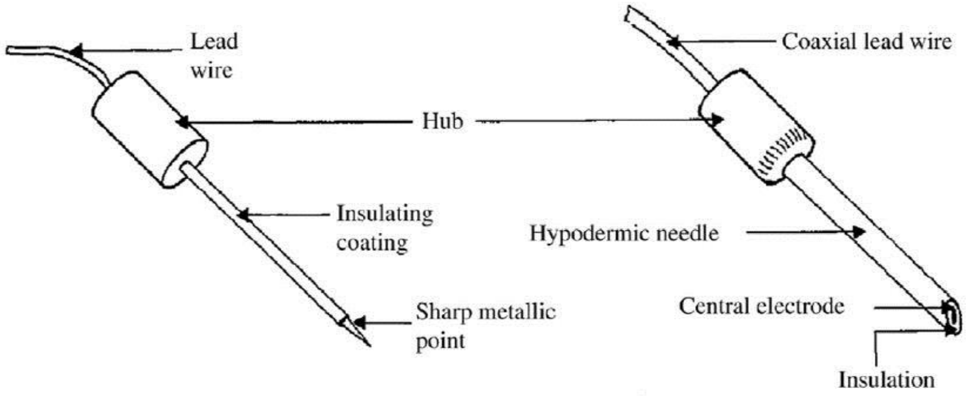
❖ Depth electrodes are placed through a small hole using stereotactic navigation to target locations identified through high-resolution imaging.

❖ Common targets include the mesial temporal lobe, inter hemispheric fissure, and per ventricular gray matter.

Needle electrode:

❖ A fine wire through which electrical current may flow when attached to a power source; used to carry high frequency electrical currents that create heat or destroy diseased tissue (called radiofrequency ablation) or seal blood vessels.

Needle electrode:



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.
- ❖ Electrode can be used to sense ECG, EEG, EMG etc.

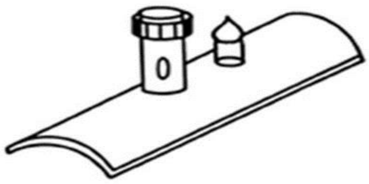
There are five types of surface electrodes

- ❖ Metal Plate electrodes
- ❖ Suction cup electrodes
- ❖ Adhesive tape electrodes
- ❖ Multi point electrodes
- ❖ Floating electrodes

1. **Metal plate electrode:**
   - ❖ One of the most frequently used forms of biopotential sensing electrodes is the metal-plate electrode.
   - ❖ In its basic form, it consists of a metallic conductor in contact with the skin.
   - ❖ An electrolyte gel is used to establish and maintain the contact.

Metal plate electrodes:

- Rectangular (3.5 cm x 5 cm) & circular (4.75 diameter) in shape
- German silver, nickel silver, nickel plated steel
- ECG measurements



2. Suction cup electrode:

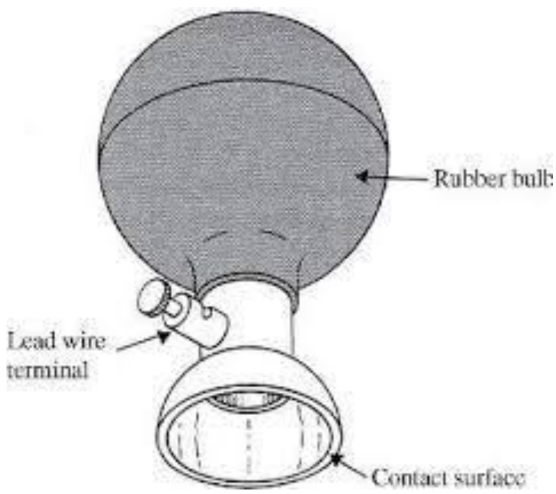
❖ To measure ECG from various positions on the chest, Suction cup electrodes are used.

❖ It suits well to attach electrodes on flat surface of the body and on soft tissue regions.

❖ They have a good contact surface. Physically they are large but the skin contacts only the electrode rim.

❖ It has high contact impedance. They have a plastic syringe barrel, suction tube and cables.

❖ Recently, due to infection and cleaning procedures, these electrodes are not used.



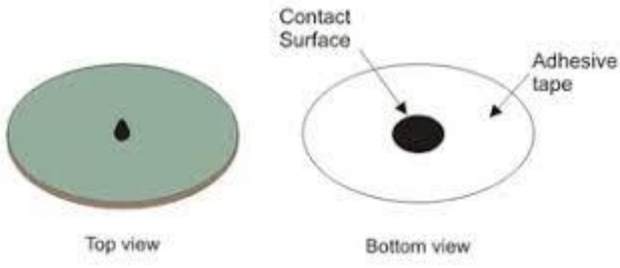
3. **Adhesive tape electrode:**

❖ In the surface electrode, the pressure of surface electrode against the skin squeezes out the electrode paste.

❖ To avoid this problem, adhesive electrodes are used. It has a lightweight metallic screen.

❖ They have a pad at behind for placing electrode paste. This adhesive backing hold the electrode on place and tight.

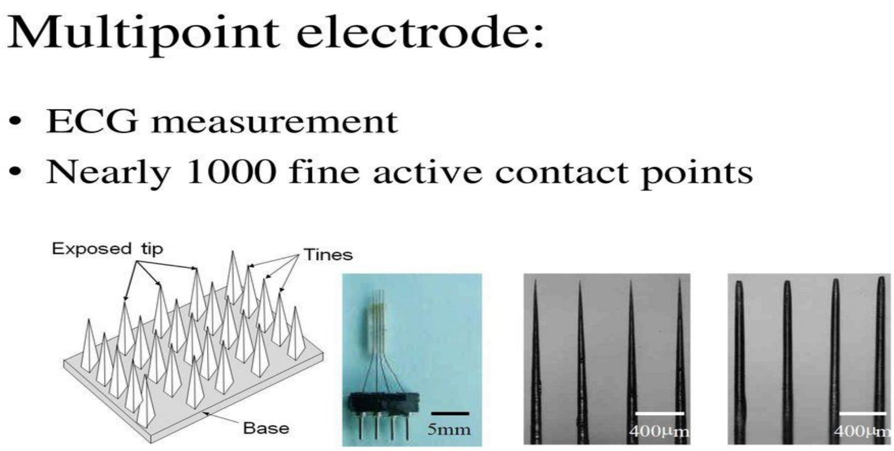
❖ It also helps to avoid evaporation of electrolyte present in the electrode paste.



4. **Multipoint electrode:**

❖ Multipoint electrodes are very practical electrode setup for ECG measurements. It has more than 1000 active contact points.

❖ This helps to establish low resistance contact with the human. Under any environmental condition, doctors can use multipoint electrode.

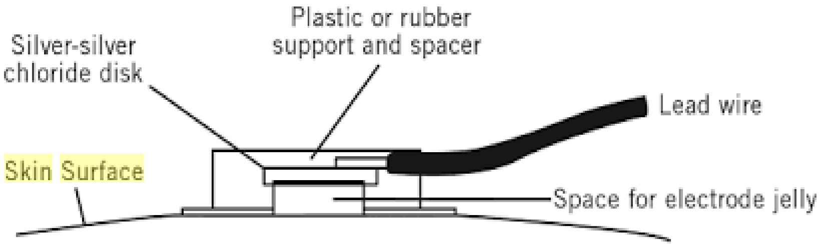


5. **Floating electrode:**

❖ In metal plate or limb electrodes, the major disadvantage is the movement errors. Motion artefact occurs due to the motion at the interface between electrode and electrolyte.

❖ The interface gets stabilized using Floating electrodes. The floating electrodes do not contact the human subject directly.

❖ They contact the subject via electrolytic paste or jelly. The advantage of this type is the mechanical stability.



2. **Brief on (May 2019)**

(a) Electrode tissue interface

(b) Polarization

a) <u>ELECTRODE TISSUE INTERFACE:</u>

❖ The most commonly used electrodes in patient monitoring and related studies are surface electrodes.

❖ The notable examples are when they are used for recording ECG, EEG and respiratory activity by impedance pneumography.

❖ In order to avoid movement artefacts and to obtain clearly established contact (low contact impedance) an electrolyte or electrode paste is usually employed as an interface between the electrode and the surface of the source of the event.

<u>Metal - Electrolyte interface:</u>

❖ The metal - Electrolyte interface appears to consist of a voltage source in series with a parallel combination of a capacitance and reaction resistance. The voltage developed is called the half-cell potential.

Metal	Ionic symbol	Electrode potential
Aluminium	Al^{+++}	–1.66V
Iron	Fe^{++}	–0.44V
Lead	Pb^{++}	–0.12V
Hydrogen	$H+$	0
Copper	C^{++}	+0.34V
Silver	$Ag+$	+0.80V
Platinum	$Pt+$	+1.2V
Gold	$Au+$	+1.69V

Table: Electrode Potential for some Metals with Respect to Hydrogen

- ❖ This table shows that the electrode potentials are appreciable when dissimilar metals are used.
- ❖ They also exist, though of smaller magnitude, even if electrodes of similar materials are employed.
- ❖ The lowest potential has been observed to be in the silver-silver chloride electrodes.
- ❖ The values of the capacitance and the resistance depend upon many factors which include the current density, temperature, type and concentration of the electrolyte and the type of metal used.
- ❖ The difference in half-cell potentials that exists between two electrodes is also called 'offset potential'.
- ❖ The differential amplifiers used to measure potentials between two electrodes are generally designed to cancel the electrode offset potential so that only the signals of interest are recorded.
- ❖ The electrode offset potential produced between electrodes may be unstable and unpredictable.
- ❖ The long-term change in this potential appears as baseline drift and short-term changes as noise on the recorded trace.
- ❖ If electrodes are used with ac-coupled amplifiers, the long term drift may be partially rejected by the low frequency characteristics of the amplifier.
- ❖ But it will depend upon the rate of change of electrode offset potential in relation to the ac-coupling time constant in the amplifier.

❖ For example, if the electrode offset potential drift rate is 1 mV/s, satisfactory results can only be obtained if the low frequency response of the amplifier is1Hz.

Electrolyte-Skin Interface:

❖ An approximation of the electrolyte-skin interface can be had by assuming that the skin acts as a diaphragm arranged between two solutions (electrolyte and body fluids) of different concentrations containing the same ions, which is bound to give potential differences.

❖ The simplest equivalent representation could then be described as a voltage source in series with a parallel combination of a capacitance and resistance.

❖ The capacitance represents the charge developed at the phase boundary whereas the resistance depends upon the conditions associated with ion-migration along the phase boundaries and inside the diaphragm.

❖ The above discussion shows that there is a possibility of the presence of voltages of non-physiological origin. These voltages are called contact potentials.

❖ The electrical equivalent circuit of the surface electrode suggests that the voltage presented to the measuring instrument from the electrode consists of two main components.

❖ One is the contact potential and the other is the biological signal of interest. The contact potential depends upon several factors and may produce an interference signal which exceeds several times the useful signal.

❖ The contact potential is found to be a function of the type of skin, skin preparation and composition of the electrolyte.

❖ When bioelectric events are recorded, interference signals are produced by the potential differences of metal-electrolyte and the electrolyte-skin interface.

❖ Normally, these potential differences are connected in opposition during the recording procedure, and in the case of a truly reversible and uniform electrode pair, their difference would be nil.

❖ However, in practice, a difference of potential may be extremely small and is found to exist between electrodes produced even under conditions of utmost care during manufacture.

❖ Also, some of the elements in the equivalent circuit are time-dependent and are bound to show slow variations with time.

b) <u>POLARIZATION:</u>

❖ If a low voltage is applied to two electrodes placed in a solution, the electrical double layers are disturbed.

❖ Depending on the metals constituting the electrodes, a steady flow of current may or may not take place.

❖ In some metal / liquid interfaces, the electrical double layer gets temporarily disturbed by the externally applied voltage, and therefore, very small current flows after the first surge, thus indicating a high resistance.

❖ This type of electrode will not permit the measurement of steady or slowly varying potentials in the tissues.

❖ They are said to, be polarized or non reversible. Thus, the phenomenon of polarization affects the electro-chemical double layer on the electrode surface and manifests itself in changing the value of the impedance and voltage source representing the transition layer.

❖ Parsons (1964) stated that electrodes in which no net transfer of charge takes place across the metal-electrolyte interface can be termed as perfectly polarized.

❖ Those in which unhindered exchange of charge is possible are called non-polarizable or reversible electrodes.

❖ The ionic double layer in metals of these electrodes is such that they allow considerable current to flow when a small voltage is applied, thus offering a low resistance.

❖ Non-polarizing electrodes on the other hand, are designed to rapidly dissipate any charge imbalance induced by powerful electrical discharges such as a defibrillation procedure.

❖ Depolarization enables the immediate reappearance of bioelectric signals on the monitor after defibrillation.

❖ For this reason, non-polarizing electrodes have become the electrodes of choice for monitoring in the intensive care units and stress testing procedures.

❖ Although polarizable electrodes are becoming less common, they are still in use.

❖ They usually employ stainless steel and are used for resting ECGs or other situations where there is small likelihood that the electrodes would be exposed to a large pulse of energy (such as a defibrillation discharge) in which case they would retain a residual charge, become polarized, and will no longer transmit the relatively small bioelectric signals, thus becoming useless.

❖ The choice of metals for electrodes is not determined only by their susceptibility to polarization, but other factors such as mechanical properties, skin irritation or skin staining, etc. have also to be taken into consideration.

3. How metal microelectrodes are formed and explain its electrical equivalent ciruit with neat diagram. (Sep 2020)

Metal Microelectrodes:

❖ Metal electrodes with very fine tips used for recording from single cells have the advantage over glass micropipetes of being relatively robust.

❖ Steel microelectrodes can be made from ordinary darning needles but preferably they should be of good stainless steel wire.

❖ They can be easily made up to 10 ▪m diameter but great care has to be taken for diameters as small as 1 ▪m.

❖ These very small tips are not very satisfactory as they are extremely brittle and have very high input impedance.

❖ Hubel (1957) described a method to make tungsten microelectrodes with a tip diameter of 0.4 m.

❖ He used electropointing technique which consists in etching a metal rod while the metal rod is slowly withdrawn from the etching solution, thus forming a tapered tip on the end of the rod.

❖ The etched metal is then dipped into an insulating solution for placing insulation on all but the tip.

❖ This arrangement offers lower impedance than the microcapillary electrode, infinite shelf life and reproduciable performance, with ease of cleaning and maintenance.

❖ The metal—electrolyte interface is between the metal film and the electrolyte of the cell.

❖ Skrzypek and Keller (1975) illustrated a new method of manufacturing tungsten microelectrode permitting close control of microelectrode para- meters.

❖ In this technique, the tips are dc electroetched to diameters below 500° A and completely covered with polymethyl methacrylate.

❖ An electron beam from a scanning electron microscope is then used to expose a precise area on the tip for later removal by chemical methods.

❖ Recording results with these electrodes suggested good desirable recording characteristics, i.e. ability to isolate and hold single cells.

❖ Tungsten is preferred for constructing micro-electrodes due to its mechanical strength and its apparent inertness.

❖ Although tungsten itself is reactive, a surface layer of tungsten oxide will, in most situations, protect the metal against corrosion.

❖ The electrical properties of tungsten microelectrodes made with a taper of the tip of about 1:10 and insulated with lacquer leaving a tip length of about 10–100 µm were studied by Zeuthen (1978).

❖ The resting potential in saline was found to be –0.3 V relative to a silver-silver chloride reference electrode for input currents less than 10–12 A.

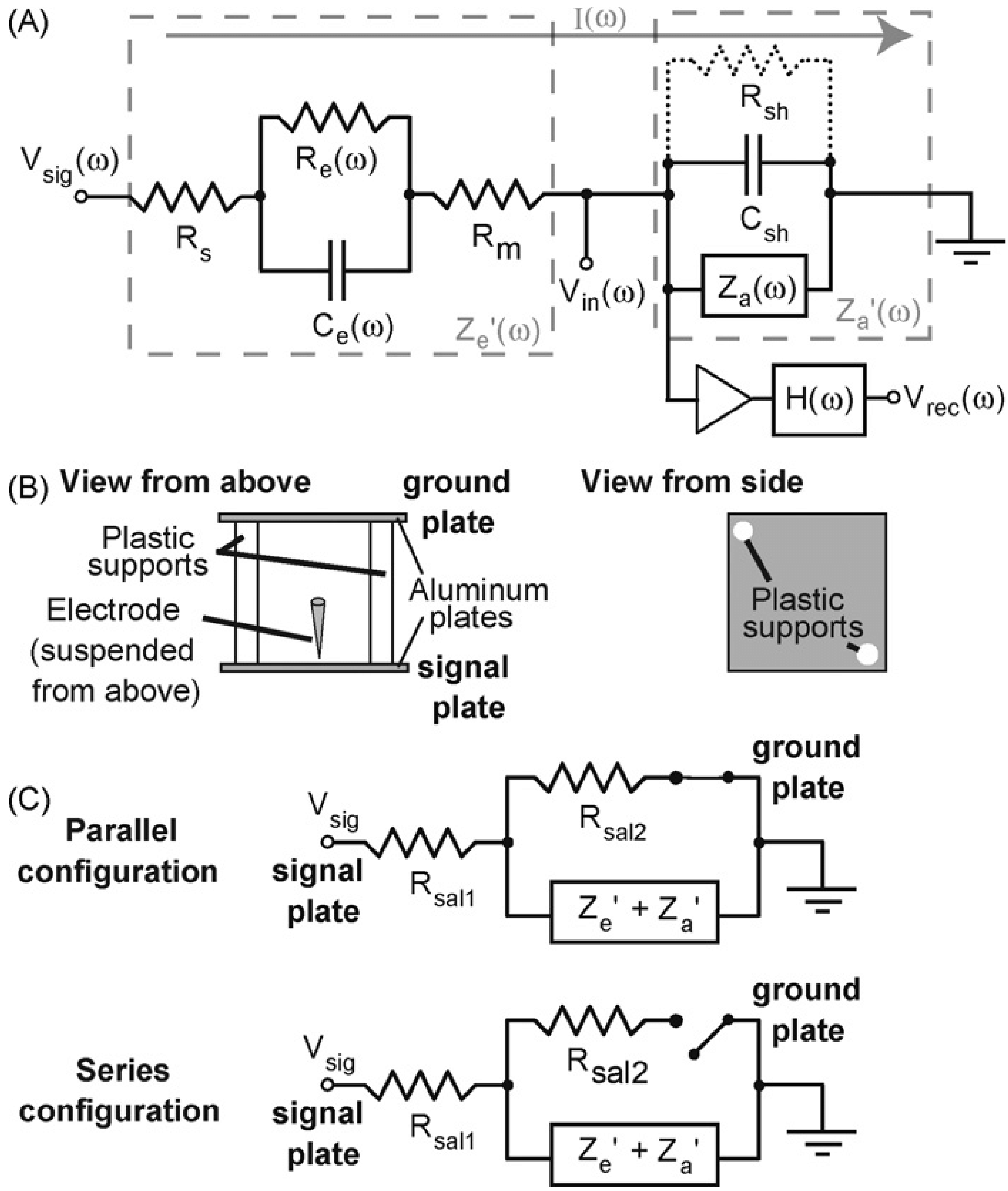
❖ Metallic electrodes are formed from a fine needle of a suitable metal drawn to a fine tip.

❖ On the other hand, glass electrodes are drawn from Pyrex glass of special grade.

❖ The metal microelectrodes are used in direct contact with the biological tissue and, therefore, have a lower resistance. However, they polarize with smaller amplifier input currents.

❖ The glass microelectrode has a substantial current carrying capacity because of the large surface contact area between the metal and the electrolyte.

Equivalent circuit:



❖ Equivalent circuit model and methods. (A) Equivalent circuit model of a metal microelectrode in the brain adapted from Robinson (1968). The entire circuit is comprised of the electrode in the brain and the amplifier with a filter.

❖ The effective impedance of the electrode (Z e) is comprised of the resistance of the electrolyte solution (R s), the resistance and capacitance at the double layer interface of the electrolyte and the un insulated electrode tip (R e and C e) and the (negligible) resistance of the metal electrode (R m).

❖ The effective input impedance of the amplifier (Z a) is comprised of the input impedance of the head-stage amplifier (Z a) and the shunt resistance and capacitance to ground from the tip of the electrode to the input of the amplifier (R sh and C sh).

❖ Two aluminium plates were connected and separated from each by non-conducting plastic supports, shown here from a top and side view.

❖ The apparatus was immersed in dilute saline with voltage signals applied to the signal plate with an electrode suspended from above 3 mm away.

4. Draw the equivalent diagram of an electrode tissue interface and explain the need of electrode jellies. (Nov 2018, May 2018)

❖ Warburg (1899) in his pioneering studies discovered that a single electrode/electrolyte interface can be represented by a series capacitance C and resistance R as shown in Fig.

❖ However, C and R are unlike real capacitors and resistors because their values are frequency and current- density dependent. Often, these components are called the polarization capacitance and resistance.

❖ The consequence of this relationship is that the phase angle ▪ is constant at ▪/4 for all frequencies.

❖ However, only a limited number of studies have tested the accuracy of the Warburg model (Ragheb and Geddes, 1990).

❖ It has been observed that the Warburg series RC equivalent does not adequately represent the behaviour of an electrode/electrolyte interface as this equivalent does not truly account for the very low-frequency behaviour of the interface.

❖ It is well known that such an interface can pass direct current. Therefore, a resistance Rf placed in parallel with the Warburg equivalent is more appropriate.

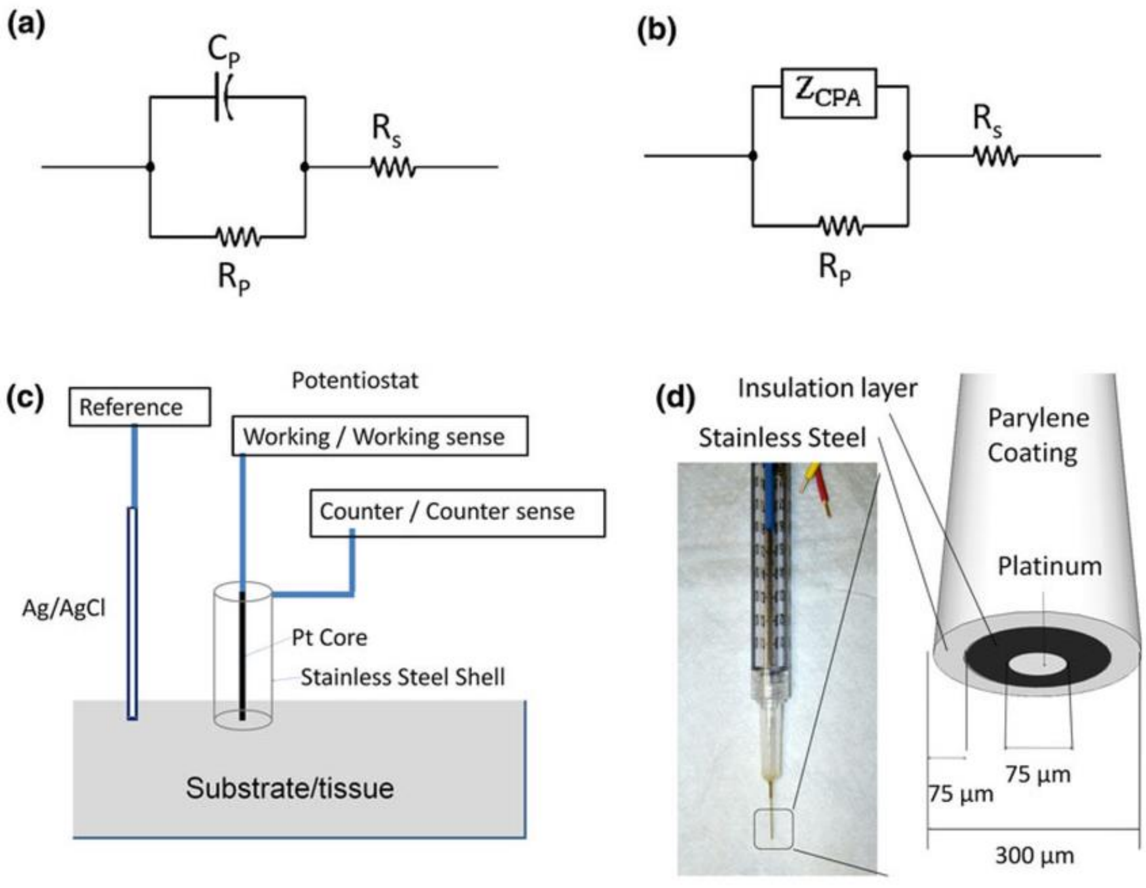
❖ The below figure shows this equivalent circuit in which Rf represents the Faradic leakage resistance. The value of Rf is high in the low-frequency region and is dependent on current density, increasing with a increase in current density.

❖ a) Equivalent circuit model of electrode–tissue interface, with interface reactance represented by a single capacitor C_P, R_P charge transfer resistance, R_S Tissue/electrolyte resistance.

❖ b) Equivalent circuit model of electrode–tissue interface, with interface reactance represented by a constant phase element (Z_{CPA}).

❖ c) Illustration of experimental setup. Ag/AgCl reference electrode, Platinum core of the concentric bipolar electrode, and Stainless steel outer shell of the bipolar electrode were connected to the potentiostat as the reference, working, and counter electrode, respectively.

❖ d) Illustration of the geometry and dimension of the bipolar electrode tip.



ELECTRODE JELLIES:

❖ Conducting creams and jellies have for long been used to facilitate a more intimate contact between the subject's skin and the recording electrodes.

❖ The outer horny layer of the skin is responsible for the bulk of the skin contact impedance, and for this reason careful skin preparation is essential in order to obtain the best results.

❖ The recording site should first be cleaned with an ether-meth mixture. In addition to having good electrical conductivity, the electrode jelly must have a particular chloride ion concentration (about 1%) close to the physiological chloride concentration.

❖ This is primarily important for long-term monitoring because it should not produce a harmful diffusion between the jelly and the body.

❖ It is to be particularly ensured that the jelly chosen is of a bland nature and does not contain soap or phenol which can produce a marked irritation of the skin after a few hours.

❖ The electrical conductivity of different makes of electrode cream can be measured (Hill and Khandpur, 1969) by means of the Schering ac bridge circuit.

❖ The cream is placed in a perspex conductivity cell of known dimensions and the resistive component of the cell impedance is measured at 10 Hz, the conductivity being calculated from the cell dimensions.

❖ The contact impedance of the skin depends upon the type of electrolyte used and the time (Trimby, 1976)

❖ A low concentration sodium chloride electrolyte has 0.5% NaCI and a high concentration electrolyte has a concentration in the range of 5 to 10% NaCI.

❖ The impedance is found to fall rapidly to 40% between 7 to 30 min. Stabilization occurs at about 30 to 45 min.

❖ An interesting observation from this figure is that while pre-rubbing the skin will lower the initial impedance value, the final value after using a high concentration electrolyte becomes nearly the same.

❖ Electrode jelly can be replaced in certain cases by using a conducting plastic as an interface between the electrode and the surface of the body.

5. Explain the construction and working of Ag/AgCl electrode. (May 2017, Nov 2016, May 2016)

❖ The silver/silver chloride or Ag/AgCl reference electrode is many electrochemists' reference electrode of choice. It is easily and cheaply prepared. It is stable, and quite robust.

❖ It is sometimes referred to as "SSCE" (Silver/Silver Chloride Electrode) but that abbreviation has been used for Sodium Saturated Calomel Electrode also.

Construction:

❖ The figure to the right shows an easily constructed Ag/AgCl reference electrode. The body of the electrode is made from 4 mm glass tube.

❖ A porous glass is available in 4 mm diameter rod and serves as the ionicly conducting electrical pathway between the inside of the reference electrode and the bulk of your cell.

❖ It has low electrical resistance (under 10 kohm for the common filling solutions) and a modest leak rate.

❖ The electrical resistance of the reference electrode 'frit' is an important factor in determining the stability and speed of your potentiostat in actual use.

❖ The leak rate may be important because of possible contamination of your solution by the reference electrode filling solution and vice versa.

Production of Silver-Silver Chloride Electrodes:

❖ Silver-silver chloride electrodes are normally prepared by electrolysis. Two silver discs are suspended in a saline solution.

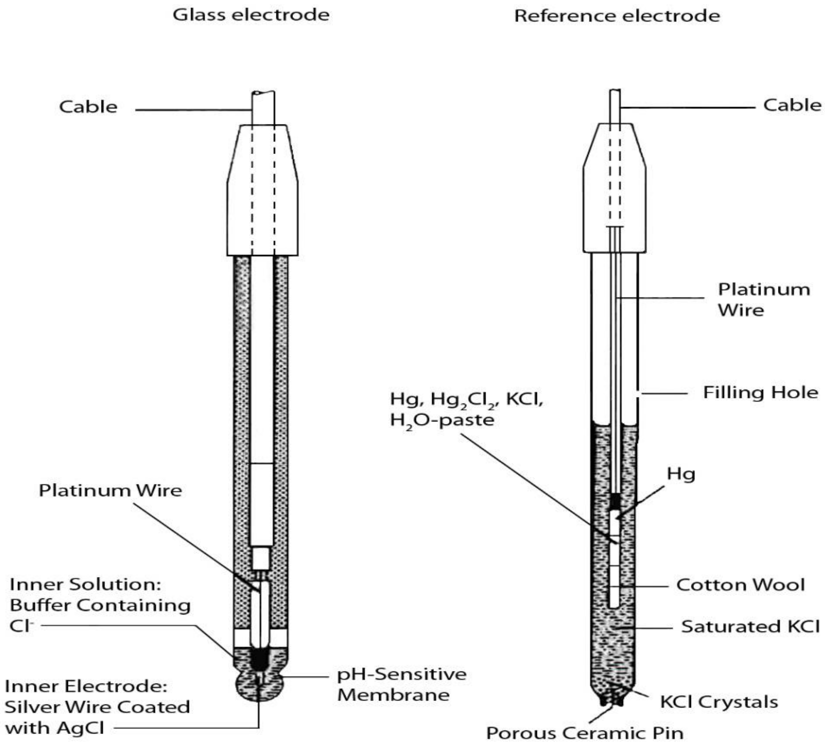
❖ The positive pole of a dc supply is connected to the disc to be chlorided and the negative pole goes to the other disc.

❖ A current at the rate of 1 mA/cm2 of surface area is passed through the electrode for several minutes.

❖ A layer of silver chloride is thus deposited on the surface of the anode. The chemical changes that take place at the anode and cathode respectively are:

❖ To prepare silver-silver chloride electrodes of good quality, only pure silver should be used and the saline solution should be made from analar grade sodium chloride. Before chloriding, silver must be cleaned—preferably by the electrolytic method.

❖ They demonstrated that the impedance was different for different layers of chloride and that there is an optimum chloriding, which gives the lowest impedance.



❖ A layer of silver chloride is thus deposited on the surface of the anode. The chemical changes that take place at the anode and cathode respectively are:

$$NaCl = Na^+ + Cl^-$$
$$Cl^- + Ag^+ = AgCl$$

❖ The positively charged sodium ions generate hydrogen when they reach the cathode surface.

$$2Na^+ + 2H_2O + 2 \text{ electrons} = 2NaOH + H_2$$

❖ They concluded that the lowest electrode-electrolyte impedance in the frequency range of 10 Hz to 10 kHz was found to occur with a chloride deposit ranging between 100 and 500 mAs/cm2 of electrode area.

❖ Higher values may be used with a corresponding reduction in time to achieve the 100–500 mAs/cm2 chloride deposit.

❖ The use of a chloride deposit in excess of this range did not alter the resistive nature of the electrode-electrolyte impedance although it increased its magnitude.

❖ Geddes (1972) confirmed that an optimal coating of silver chloride applied to a silver electrode minimizes the electrical impedance.

❖ This is supported by Getzel and Webster (1976) who concluded that silver chloride may be applied to cleaned silver electrodes in the amount of 1050–1350 mA s/cm2 in order to reduce the impedance of the electrodes.

❖ However, to further reduce the impedance of the electrodes, they should be coated with at least 2000 mAs/cm2 of silver chloride followed by immersion in a photographic developer for 3 minutes.

❖ Grubbs and Worley (1983) obtained a lower and more stable impedance electrode by placing a heavier initial chloride coat on an etched silver electrode, and then electrolytically removing a portion of that coat.

❖ The electrode functions as a redox electrode and the equilibrium is between the silver metal (Ag) and its salt—silver chloride (AgCl, also called silver(I) chloride).

The corresponding half-reactions can be presented as follows:

$$Ag^{+} + e^{-} \text{ ----- } Ag(s)$$
$$AgCl(s) + e^{-} \text{ ------ } Ag(s) + Cl-$$

or can be written together:

$$AgCl(s) + Ag(s) + e^{-} \text{ --------- } Ag(s) + e^{-} + Ag+ + Cl^{-}$$

which can be simplified:

$$AgCl(s) \text{ ------- } Ag^{+} + Cl^{-}$$

❖ This reaction is characterized by fast electrode kinetics, meaning that a sufficiently high current can be passed through the electrode with 100% efficiency of the redox reaction.

❖ The reaction has been proven to obey these equations in solutions of pH values between 0 and 13.5.

❖ The Nernst equation below shows the dependence of the potential of the silver-silver chloride electrode on the activity or effective concentration of chloride-ions:

$$E = E_0 – RT/F \ln(Cl^{-})$$

- The standard electrode potential E0 against standard hydrogen electrode (SHE) is 0.230 V ± 10 mV. The potential is however very sensitive to traces of bromide ions which make it more negative.

Application of Ag/AgCl

- An Ag/AgCl electrode used as a corrosion sensor in a reinforced concrete structure is considered as having good application prospect.

6. Describe about the placement of electrodes for ECG and EEG. (May 2017, May 2015)

Placement of electrodes for ECG:

3-electrode system

- Uses 3 electrodes (RA, LA and LL)
- Monitor displays the bipolar leads (I, II and III)
- To get best results – Place electrodes on the chest wall equidistant from the heart (rather than the specific limbs)

5-electrode system

- Uses 5 electrodes (RA, RL, LA, LL and Chest)
- Monitor displays the bipolar leads (I, II and III)
- AND a single unipolar lead (depending on position of the brown chest lead (positions V1–6))

12-lead ECG

- 10 electrodes required to produce 12-lead ECG
- 4 Electrodes on all 4 limbs (RA, LL, LA, RL)6 Electrodes on precordium (V1–6)
- Monitors 12 leads (V1–6), (I, II, III) and (aVR, aVF, aVL)
- Allows interpretation of specific areas of the heart
- Inferior (II, III, aVF)Lateral (I, aVL, V5, V6)Anterior (V1–4)

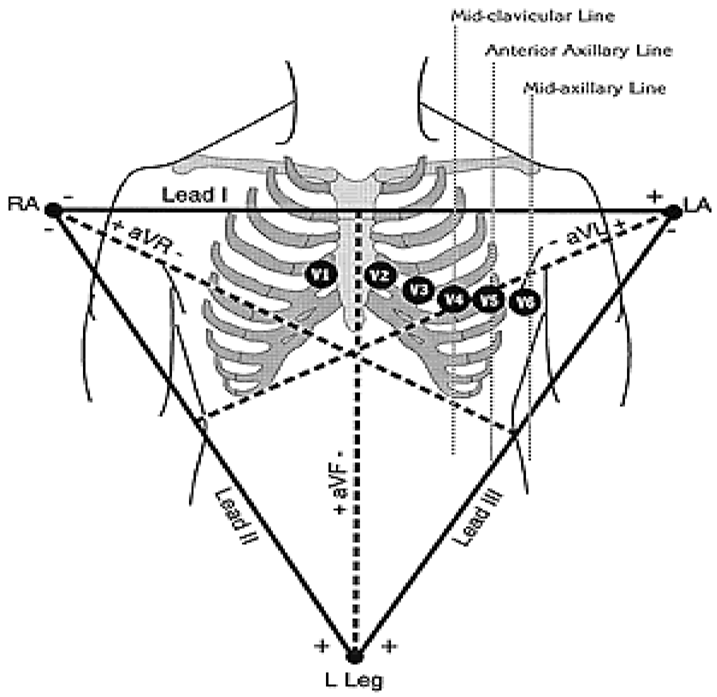
12-lead Precordial lead placement

- V1: 4th intercostal space (ICS), RIGHT margin of the sternum
- V2: 4th ICS along the LEFT margin of the sternum
- V4: 5th ICS, mid-clavicular line

❖ V3: midway between V2 and V4

❖ V5: 5th ICS, anterior axillary line (same level as V4)

❖ V6: 5th ICS, mid-axillary line (same level as V4)



Additional Lead placements

Right sided ECG electrode placement

There are several approaches to recording a right-sided ECG:

❖ A complete set of right-sided leads is obtained by placing leads V1-6 in a mirror-image position on the right side of the chest (see diagram, below).

❖ It can be simpler to leave V1 and V2 in their usual positions and just transfer leads V3-6 to the right side of the chest (i.e. V3R to V6R).

❖ The most useful lead is V4R, which is obtained by placing the V4 electrode in the 5th right intercostal space in the mid-clavicular line.

❖ ST elevation in V4R has a sensitivity of 88%, specificity of 78% and diagnostic accuracy of 83% in the diagnosis of RV MI.

V4R ECG lead placement

- ❖ Erhardt et al first described the use of a right sided precordial lead (CR4R or V4R) in the diagnosis of right ventricular infarction which had previously been thought to be electrocardiographically silent.
- ❖ Single right-sided precordial lead in the diagnosis of right ventricular involvement in inferior myocardial infarction.

Posterior leads

Leads V7-9 are placed on the posterior chest wall in the following positions:

- ❖ V7 – Left posterior axillary line, in the same horizontal plane as V6.
- ❖ V8 – Tip of the left scapula, in the same horizontal plane as V6.
- ❖ V9 – Left paraspinal region, in the same horizontal plane as V6.

Lewis lead(S5-lead)

Lewis lead placement

- ❖ Right Arm (RA) electrode on manubrium
- ❖ Left Arm (LA) electrode over 5th ICS, right sternal border.
- ❖ Left Leg (LL) electrode over right lower costal margin.

Fontaine leads:

Fontaine bipolar precordial leads (F-ECG) are used to increase the sensitivity of epsilon wave detection. Named after French cardiologist and electrophysiolgist Guy Hugues Fontaine (1936-2018). Leads are placed as shown:

- ❖ Right Arm (RA) over the manubrium;
- ❖ Left Arm (LA) over the xiphoid process;
- ❖ and Left Leg (LL) in the standard V4 position (5th ICS MCL).

Instead of regular leads I, II, and III there are now three bipolar chest leads that are termed FI, FII, and FIII which record the potentials developed in the right ventricle, from the infundibulum to the diaphragm.

The vertical bipolar lead FI, (similar to aVF) magnifies the atrial potentials and can be used to record:

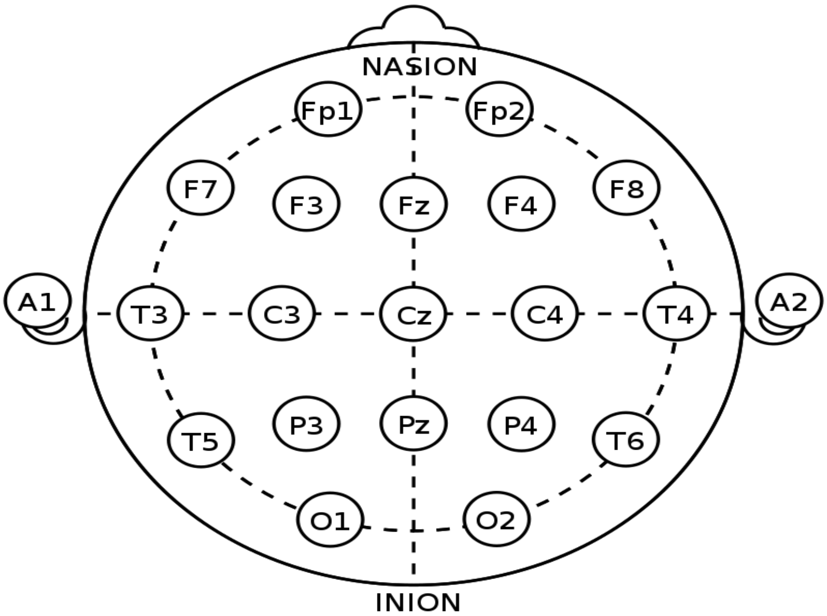
- ❖ Epsilon waves;
- ❖ Search for AV dissociation in ventricular tachycardia;
- ❖ And to study abnormal atrial rhythms when the P waves are too small on regular leads.

Placement of electrodes for EEG:

- ❖ The Fp2, F8, T4, T6, and O2 electrodes are placed at intervals of 5%, 10%, 10%, 10%, 10%, and 5%, respectively, measured above the right ear, from front (Fpz) to back (Oz).
- ❖ The same is done for the odd-numbered electrodes on the left side, to complete the full circumference.

10–20 system (EEG)

- ❖ The 10–20 system or International 10–20 system is an internationally recognized method to describe and apply the location of scalp electrodes in the context of an EEG exam, polysomnograph sleep study, or voluntary lab research.
- ❖ This method was developed to maintain standardized testing methods ensuring that a subject's study outcomes (clinical or research) could be compiled, reproduced, and effectively analyzed and compared using the scientific method.
- ❖ The system is based on the relationship between the location of an electrode and the underlying area of the brain, specifically the cerebral cortex.
- ❖ During sleep and wake cycles, the brain produces different, objectively recognized and distinguishable electrical patterns, this can be detected by electrodes on the skin.
- ❖ The "10" and "20" refer to the fact that the actual distances between adjacent electrodes are either 10% or 20% of the total front–back or right–left distance of the skull. For example, a measurement is taken across the top of the head, from the nasion to inion.
- ❖ Most other common measurements ('landmarking methods') start at one ear and end at the other, normally over the top of the head. Specific anatomical locations of the ear used include the tragus, the auricle and the mastoid.



Electrode labeling:

- ❖ Each electrode placement site has a letter to identify the lobe, or area of the brain it is reading from: pre-frontal (Fp), frontal (F), temporal (T), parietal (P), occipital (O), and central (C).
- ❖ Note that there is no "central lobe"; due to their placement, and depending on the individual, the "C" electrodes can exhibit/represent EEG activity more typical of frontal, temporal, and some parietal-occipital activity, and are always utilized in polysomnography sleep studies for the purpose of determining stages of sleep.
- ❖ There are also (Z) sites: A "Z" (zero) refers to an electrode placed on the midline sagittal plane of the skull, (FpZ, Fz, Cz, Oz) and is present mostly for reference/measurement points.
- ❖ These electrodes will not necessarily reflect or amplify lateral hemispheric cortical activity as they are placed over the corpus callosum, and do not represent either hemisphere adequately.
- ❖ Even-numbered electrodes (2,4,6,8) refer to electrode placement on the right side of the head, whereas odd numbers (1,3,5,7) refer to those on the left; this applies to both EEG and EOG (electrooculogram measurements of eyes) electrodes, as well as ECG (electrocardiography measurements of the heart) electrode placement.

- ❖ Chin, or EMG (electromyogram) electrodes are more commonly just referred to with "right," "left," and "reference," or "common," as there are usually only three placed, and they can be differentially referenced from the EEG and EOG reference sites.
- ❖ The "A" (sometimes referred to as "M" for mastoid process) refers to the prominent bone process usually found just behind the outer ear (less prominent in children and some adults). In basic polysomnography, F3, F4, Fz, Cz, C3, C4, O1, O2, A1, A2 (M1, M2), are used.
- ❖ Cz and Fz are 'ground' or 'common' reference points for all EEG and EOG electrodes, and A1-A2 are used for contralateral referencing of all EEG electrodes.
- ❖ This EEG montage may be extended to utilize T3-T4, P3-P4, as well as others, if an extended or "seizure montage" is called for.

Measurement:

- ❖ Specific anatomical landmarks are used for the essential measuring and positioning of the EEG electrodes. These are found with a tape measure, and often marked with a grease pencil, or "China marker."
- ❖ Nasion to Inion: the nasion is the distinctly depressed area between the eyes, just above the bridge of the nose, and the inion, is the crest point of back of the skull, often indicated by a bump (the prominent occipital ridge, can usually be located with mild palpation). Marks for the Z electrodes are made between these points along the midline, at intervals of 10%, 20%, 20%, 20%, 20% and 10%.
- ❖ Preauricular to preauricular (or tragus to tragus: the tragus refers to the small portion of cartilage projecting anteriorly to the pinna).
- ❖ The preauricural point is in front of each ear, and can be more easily located with mild palpation, and if necessary, requesting patient to open mouth slightly.
- ❖ The T3, C3, Cz, C4, and T4 electrodes are placed at marks made at intervals of 10%, 20%, 20%, 20%, 20% and 10%, respectively, measured across the top of the head.
- ❖ Skull circumference is measured just above the ears (T3 and T4), just above the bridge of the nose (at Fpz), and just above the occipital point (at Oz). The Fp2, F8, T4, T6, and O2 electrodes are placed at intervals of 5%, 10%, 10%, 10%, 10%, and

5%, respectively, measured above the right ear, from front (Fpz) to back (Oz). The same is done for the odd-numbered electrodes on the left side, to complete the full circumference.

❖ Measurement methods for placement of the F3, F4, P3, and P4 points differ. If measured front-to-back (Fp1-F3-C3-P3-O1 and Fp2-F4-C4-P4-O2 montages), they can be 25% "up" from the front and back points (Fp1, Fp2, O1, and O2).

❖ If measured side-to-side (F7-F3-Fz-F4-F8 and T5-P3-Pz-P4-T6 montages), they can be 25% "up" from the side points (F7, F8, T5, and T6).

❖ If measured diagonally, from Nasion to Inion through the C3 and C4 points, they will be 20% in front of and behind the C3 and C4 points. Each of these measurement methods results in different nominal electrode placements.

7. Write in detail notes on electrical conductivity of jellies and its types.(May 2017)

ELECTRICAL CONDUCTIVITY OF ELECTRODE JELLIES:

❖ Conducting creams and jellies have for long been used to facilitate a more intimate contact between the subject’s skin and the recording electrodes.

❖ The outer horny layer of the skin is responsible for the bulk of the skin contact impedance, and for this reason careful skin preparation is essential in order to obtain the best results.

❖ The recording site should first be cleaned with an ether-meth mixture. In addition to having good electrical conductivity, the electrode jelly must have a particular chloride ion concentration (about 1%) close to the physiological chloride concentration.

❖ This is primarily important for long-term monitoring because it should not produce a harmful diffusion between the jelly and the body.

❖ It is to be particularly ensured that the jelly chosen is of a bland nature and does not contain soap or phenol which can produce a marked irritation of the skin after a few hours.

❖ The electrical conductivity of different makes of electrode cream can be measured (Hill and Khandpur, 1969) by means of the Schering ac bridge circuit.

❖ The cream is placed in a perspex conductivity cell of known dimensions and the resistive component of the cell impedance is measured at 10 Hz, the conductivity being calculated from the cell dimensions.

❖ The contact impedance of the skin depends upon the type of electrolyte used and the time (Trimby, 1976)

❖ A low concentration sodium chloride electrolyte has 0.5% NaCI and a high concentration electrolyte has a concentration in the range of 5 to 10% NaCI.

❖ The impedance is found to fall rapidly to 40% between 7 to 30 min. Stabilization occurs at about 30 to 45 min.

❖ An interesting observation from this figure is that while pre-rubbing the skin will lower the initial impedance value, the final value after using a high concentration electrolyte becomes nearly the same.

❖ Electrode jelly can be replaced in certain cases by using a conducting plastic as an interface between the electrode and the surface of the body.

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❖ An interesting observation from this figure is that while pre-rubbing the skin will lower the initial impedance value, the final value after using a high concentration electrolyte becomes nearly the same.

❖ Electrode jelly can be replaced in certain cases by using a conducting plastic as an interface between the electrode and the surface of the body.

❖ Jenkner (1967) used silastic S-2086 by Dow Corning with EEG electrodes and showed that contact resistance was almost the same as with a conventional electrode which make use of electrode jelly.

TYPES OF GEL:

PEO - BASED POLYMER GEL ELECTROLYTE:

❖ For preparation of this electrolyte EC and/or PC are taken as plasticizers. LiClO4, LiCFSO3, LiN(SO2CF3)2 etc are used as the salt.

- This electrolyte has a conductivity of 10-3 Scm-1 . The polymer used (i.e. PEO) is not soluble to a greater extent with the solvent resulting in poor mechanical strength of the gels.

PAN - BASED POLYMER GEL ELECTROLYTE:

- The polymer used is PAN (Polyacrylonitrile). Lithium salts are the principle salt used here.
- The Li+ ion transference number were found to be very high in case of PAN- based gel electrolyte.

PMMA - BASED POLYMER GEL ELECTROLYTE:

- The polymer, solvent and salt are PMMA, EC and/or PC and Lithium and sodium salts respectively.
- An ionic conductivity of 10-3 S cm-1 has been achieved in this gel electrolyte.

PVDF - BASED POLYMER GEL ELECTROLYTE:

- PVDF is the polymer, EC/PC or DMF is the solvent and lithium salts such as LiCF3SO3, LiPF6 or LiN(SO3CF3)2 or NaI is mainly taken as the salt.
- PVDF based gel has good electrochemical properties but they are reactive to lithium and lithium salts.

BM T46 – BIOMEDICAL SENSORS AND TRANSDUCERS

UNIT - 5

2 MARKS

1. **What are the basic components of sensor? (SEP 2020)**
   - A sensor node is made up of four basic components such as sensing unit, processing unit, transceiver unit and a power.
   - It also has application dependent additional components such as a location finding system, a power generator and a mobilizer.

2. **Mention the need of measurement of PO2. (SEP 2020)**
   - PO2 (partial pressure of oxygen) reflects the amount of oxygen gas dissolved in the blood.
   - It primarily measures the effectiveness of the lungs in pulling oxygen into the blood stream from the atmosphere.
   - Elevated pO2 levels are associated with: Increased oxygen levels in the inhaled air.
   - This is measured by a pO2 electrode.

3. **Define a biosensor. (MAY 2019, NOV 2017, MAY 2016, MAY 2015, NOV 2015)**
   - A biosensor is an analytical device, used for the detection of a chemical substance that combines a biological component with a physicochemical detector.
   - Biosensors consist of three parts: a component that recognizes the analyte and produces a signal, a signal transducer, and a reader device.

4. **What is ISFET? (MAY 2019)**
   - An ion-sensitive field-effect transistor (ISFET) is a field-effect transistor used for measuring ion concentrations in solution.
   - When the ion concentration (such as H+, see pH scale) changes, the current through the transistor will change accordingly. Here, the solution is used as the gate electrode.

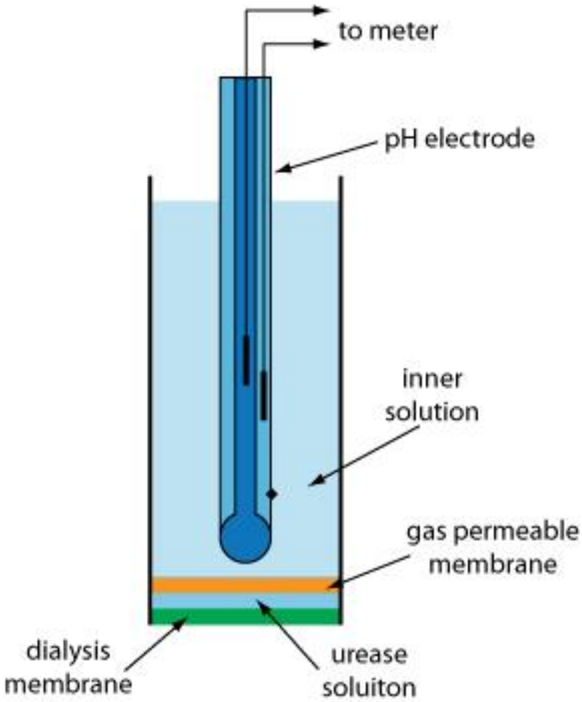
5. **Give the classification of Biosensors. (NOV 2018, MAY 2018)**
   - Electrochemical Biosensors - Electrochemical biosensors react with an analyte of interest to product an electrical signal proportional to the analyte concentration.
   - Immuno sensors.

- ❖ Magnetic Biosensors.
- ❖ Thermometric Biosensors.
- ❖ Acoustic Biosensors.
- ❖ Optical Biosensors.

6. How does pH measurement help in blood gas analysis? (NOV 2018, MAY 2018)

- ❖ Arterial blood pH, which indicates the amount of hydrogen ions in blood.
- ❖ A pH of less than 7.0 is called acidic, and a pH greater than 7.0 is called basic, or alkaline.
- ❖ A lower blood pH may indicate that your blood is more acidic and has higher carbon dioxide levels.

7. Draw the structure of enzyme electrode. (NOV 2017)



8. Define pH. (MAY 2017)

- ❖ pH quantitative measure of the acidity or basicity of aqueous or other liquid solutions.
- ❖ Acidic solutions are measured to have lower pH values than basic or alkaline solutions.

$$pH = -\log [H_3O^+].$$

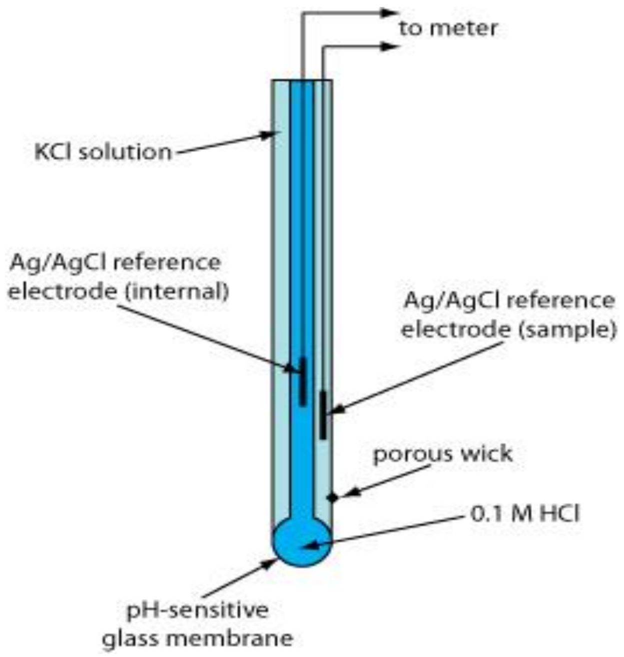
9. What is meant by Chemoreceptor? (MAY 2017, NOV 2016)

- Chemoreceptor detects changes in the normal environment, such as an increase in blood levels of carbon dioxide (hypercapnia) or a decrease in blood levels of oxygen (hypoxia), and transmits that information to the central nervous system which engages body responses to restore homeostasis.
- Chemoreceptor detects the levels of carbon dioxide in the blood by monitoring the concentrations of hydrogen ions in the blood.

10. Write the role of Calomel electrode in pH meter. (NOV 2016)

- Calomel is used as the interface between metallic mercury and a chloride solution in a saturated calomel electrode, which is used in electrochemistry to measure pH and electrical potentials in solutions.
- The pH-responsive electrode is usually glass, and the reference is usually a silver – silver chloride electrode, although a mercury – mercurous chloride (calomel) electrode is sometimes used.

11. Draw the Ph electrode. (MAY 2016)



12. What is meant by baroreceptor. (MAY 2015)

- Baroreceptors are mechanoreceptors located in the carotid sinus and in the aortic arch.

- Their function is to sense pressure changes by responding to change in the tension of the arterial wall.
- The baroreflex mechanism is a fast response to changes in blood pressure.

13. Write the principle of ISFET. (NOV 2015)

- The working principle of an ISFET pH electrode is a change of normal field effect transistor and they are used in many amplifier circuits.
- In the ISFET normally the input is used as metal gates, which are replaced by the ion-sensitive membrane.

11-MARKS

1. Discuss about the different types of receptors. (SEP 2020, MAY 2019)

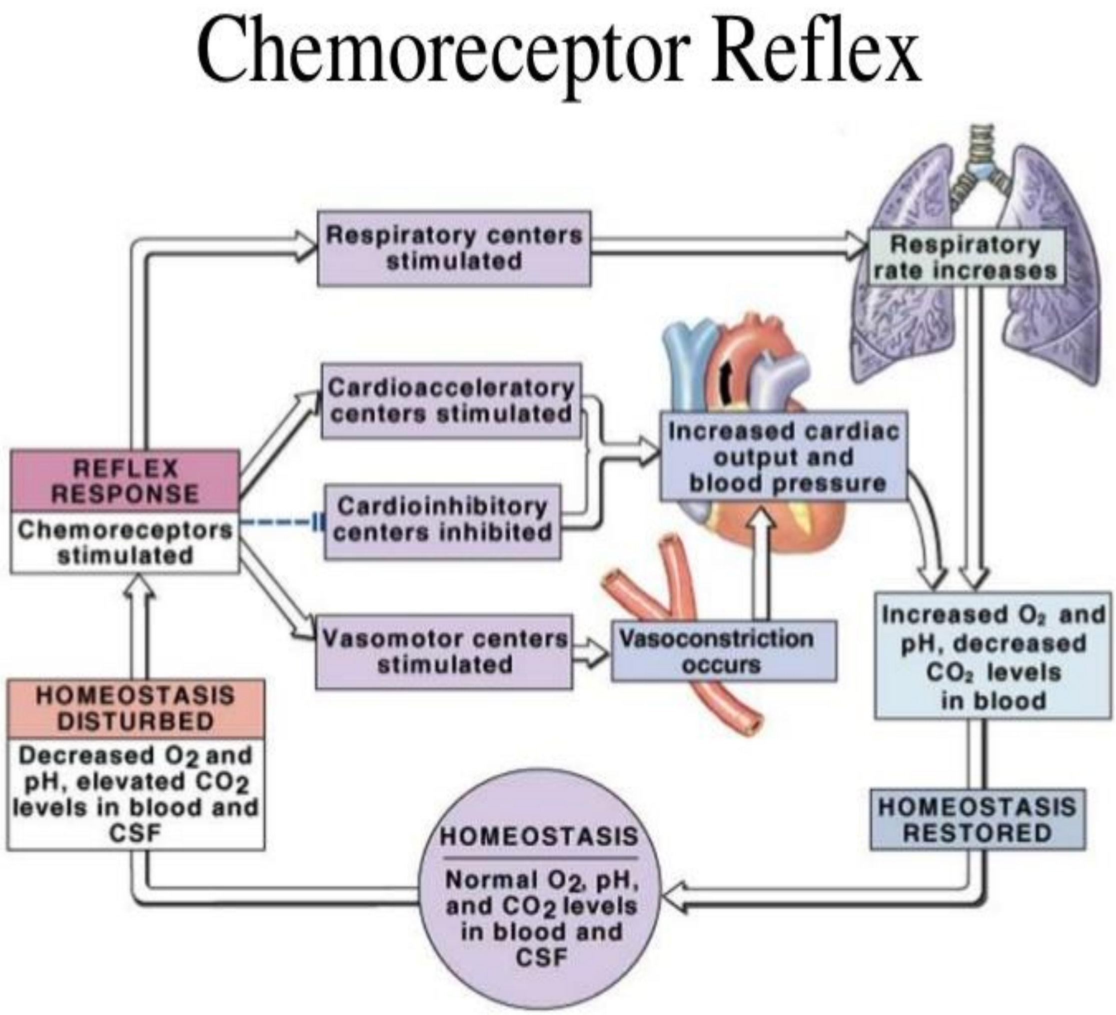
RECEPTOR:

- Receptors are chemical structures, composed of protein, that receive and transduce signals that may be integrated into biological systems.
- These signals are typically chemical messengers which bind to a receptor and cause some form of cellular/tissue response, e.g. a change in the electrical activity of a cell.

CHEMORECEPTOR:

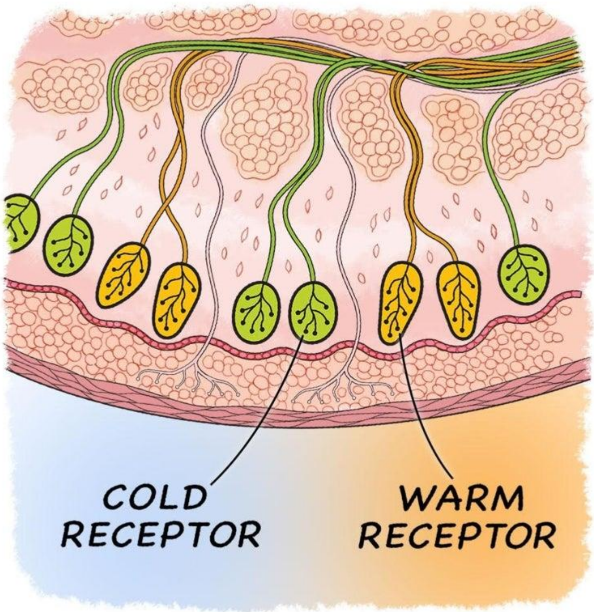
- A chemoreceptor, also known as chemo sensor, is a specialized sensory receptor cell which transduces a chemical substance (endogenous or induced) to generate a biological signal.
- This signal may be in the form of an action potential, if the chemoreceptor is a neuron, or in the form of a neurotransmitter that can activate a nerve fibre if the chemoreceptor is a specialized cell, such as taste receptors, or an internal peripheral chemoreceptor, such as the carotid bodies.
- In physiology, a chemoreceptor detects changes in the normal environment, such as an increase in blood levels of carbon dioxide (hypercapnia) or a decrease in blood levels of oxygen (hypoxia), and transmits that information to the central nervous system which engages body responses to restore homeostasis.
- Chemoreceptors detect the levels of carbon dioxide in the blood by monitoring the concentrations of hydrogen ions in the blood.

- Central chemoreceptors, located in the respiratory centre at the base of your brain, monitor the levels of carbon dioxide and oxygen by detecting changes in the pH levels of the cerebral spinal fluid.
- The chemoreceptor trigger zone (CTZ) is an area of the medulla oblongata that receives inputs from blood-borne drugs or hormones, and communicates with other structures in the vomiting centre to initiate vomiting.
- Chemoreceptors in the carotid bodies and aortic arch are sensitive to changes in arterial carbon dioxide, oxygen, and pH.
- The carotid bodies are generally more important in mediating this response and provide the principal mechanism by which mammals sense lowered levels of oxygen.
- Examples of direct chemoreceptors are taste buds, which are sensitive to chemicals in the mouth, and the carotid bodies and aortic goodies that detect changes in pH inside the body



- There are two kinds of respiratory chemoreceptors:
- **Arterial chemoreceptors,** which monitor and respond to changes in the partial pressure of oxygen and carbon dioxide in the arterial blood.
- Arterial chemoreceptors located in the aortic and carotid bodies (CBs) respond to hypoxemia and hypercapnia.
- **Central chemoreceptors** in the brain, which respond to changes in the partial pressure of carbon dioxide in their immediate.
- When changes are detected, the receptors send impulses to the respiratory centres in the brainstem that initiate changes in ventilation to restore normal pCO_2.
- Central chemoreceptors are located in the medulla oblongata of the brainstem.
- When changes are detected, the receptors send impulses to the respiratory centres in the brainstem that initiate changes in ventilation to restore normal pCO_2.
- Eg: if your O_2 level are too low central and arterial chemoreceptor convey a message that triggers an increase in respiration.

<u>Hot and Cold receptor:</u>



- Warm receptors will turn up their signal rate when they feel warmth or heat transfer into the body.
- Cooling or heat transfer out of the body results in a decreased signal rate.
- Cold receptors, on the other hand, increase their firing rate during cooling and decrease it during warming.

- There are thermoreceptors that are located in the dermis, skeletal muscles, liver, and hypothalamus that are activated by different temperatures.
- These thermoreceptors, which have free nerve endings, include only two types of thermoreceptors that signal innocuous warmth and cooling respectively in our skin.
- Thermoreceptors are able to detect heat and cold and are found throughout the skin in order to allow sensory reception throughout the body.
- Thermoreceptors are important for detecting temperature so that the body can correct for any major changes.
- Cold-sensitive thermoreceptors give rise to the sensations of cooling, cold and freshness.
- In the cornea cold receptors are thought to respond with an increase in firing rate to cooling produced by evaporation of lacrimal fluid 'tears' and thereby to elicit a blink reflex.
- Separate receptors for warmth and cold exist; with the cold receptors located close to the surface of the skin in the epidermis and the warmth receptors located deep within the dermis.

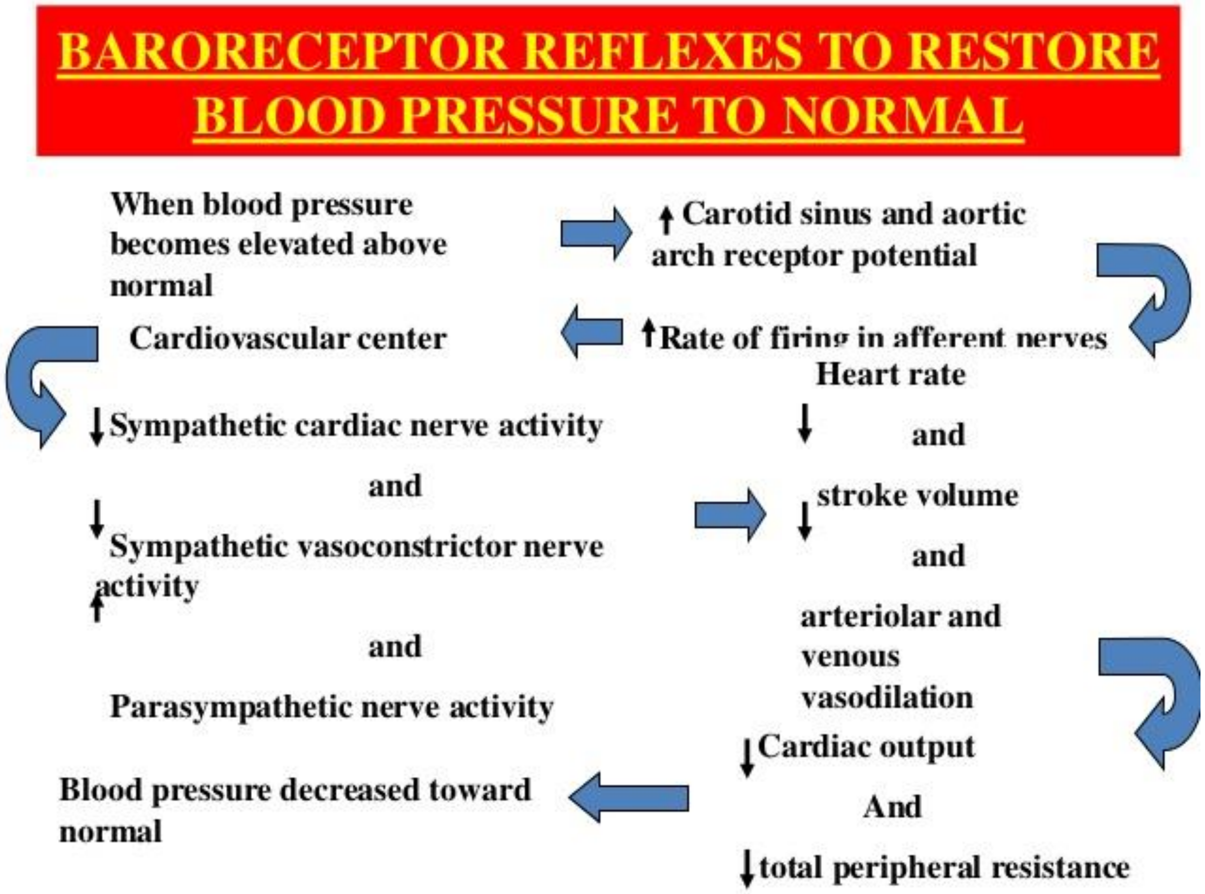
BARORECEPTOR:

- Baroreceptors are mechanoreceptors located in the carotid sinus and in the aortic arch.
- Their function is to sense pressure changes by responding to change in the tension of the arterial wall.
- The baroreflex mechanism is a fast response to changes in blood pressure.
- Baroreceptors (or archaically, pressoreceptors) are sensors located in the carotid sinus (at the bifurcation of external and internal carotids) and in the aortic arch.
- They sense the blood pressure and relay the information to the brain, so that a proper blood pressure can be maintained.
- Baroreceptors are a type of mechanoreceptor sensory neuron that are excited by a stretch of the blood vessel.
- Thus, increases in the pressure of blood vessel triggers increased action potential generation rates and provides information to the central nervous system.
- This sensory information is used primarily in autonomic reflexes that in turn influence the heart cardiac output and vascular smooth muscle to influence total peripheral resistance.

- ❖ Baroreceptors act immediately as part of a negative feedback system called the baroreflex, as soon as there is a change from the usual mean arterial blood pressure, returning the pressure toward a normal level.
- ❖ These reflexes help regulate short-term blood pressure.
- ❖ The solitary nucleus in the medulla oblongata of the brain recognizes changes in the firing rate of action potentials from the baroreceptors, and influences cardiac output and systemic vascular resistance.
- ❖ Baroreceptors can be divided into two categories based on the type of blood vessel in which they are located:
- ❖ High-pressure arterial baroreceptors and low-pressure baroreceptors (also known as cardiopulmonary or volume receptors).

Arterial Baroreceptor:

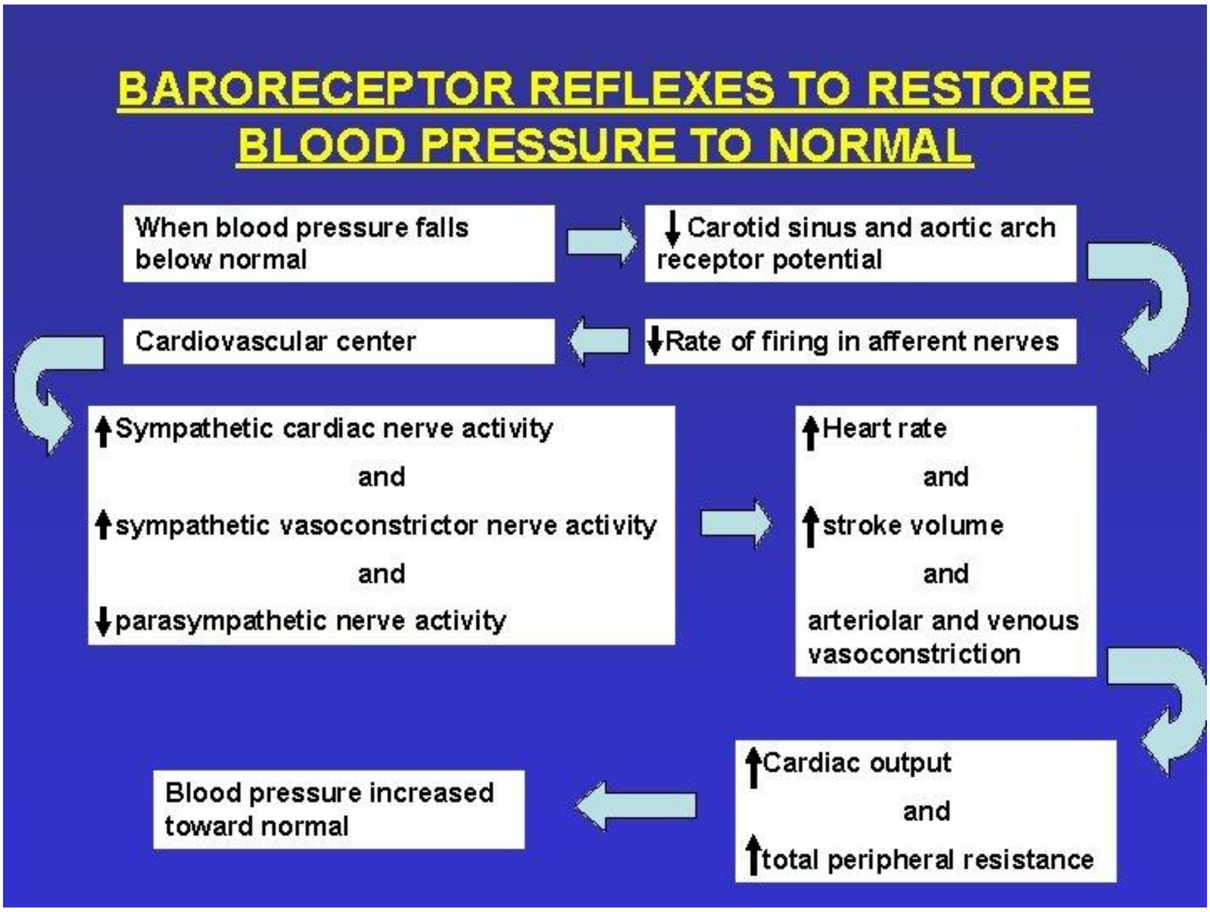
- ❖ Arterial baroreceptors are stretch receptors that are stimulated by distortion of the arterial wall when pressure changes.
- ❖ The baroreceptors can identify the changes in both the average blood pressure or the rate of change in pressure with each arterial pulse.



- Action potentials triggered in the baroreceptor ending are then directly conducted to the brainstem where central terminations (synapses) transmit this information to neurons within the solitary nucleus which lies in the medulla.
- Reflex responses from such baroreceptor activity can trigger increases or decreases in the heart rate.
- Arterial baroreceptor sensory endings are simple, splayed nerve endings that lie in the tunica adventitia of the artery.
- An increase in the mean arterial pressure increases depolarization of these sensory endings, which results in action potentials.
- These action potentials are conducted to the solitary nucleus in the central nervous system by axons and have a reflex effect on the cardiovascular system through autonomic neurons.

Low Pressure Baroreceptor:

- The low-pressure baroreceptors are found in large systemic veins, in pulmonary vessels, and in the walls of the right atrium and ventricles of the heart (the atrial volume receptors).



- The low-pressure baroreceptors are involved with the regulation of blood volume.
- The blood volume determines the mean pressure throughout the system, in particular in the venous side where most of the blood is held.
- The low-pressure baroreceptors have both circulatory and renal effects; they produce changes in hormone secretion, resulting in profound effects on the retention of salt and water; they also influence intake of salt and water.
- The renal effects allow the receptors to change the mean pressure in the system in the long term.

2. Explain the mechanism of transducer used for the measurement of ions and dissolved gases. (SEP 2020, MAY 2015, NOV 2015)

- An ion-selective electrode (ISE), also known as a specific ion electrode (SIE), is a transducer (or sensor) that converts the activity of a specific ion dissolved in a solution into an electrical potential.
- The voltage is theoretically dependent on the logarithm of the ionic activity, according to the Nernst equation.
- Ion-selective electrodes are used in analytical chemistry and biochemical /biophysical research, where measurements of ionic concentration in an aqueous solution are required.

Types of ion selective membrane:

There are four main types of ion-selective membrane used in ion-selective electrodes (ISEs): glass, solid state, liquid based and compound electrode.

Glass membranes:

- Glass membranes are made from an ion-exchange type of glass (silicate or chalcogenide).
- This type of ISE has good selectivity, but only for several single-charged cations mainly H+, Na+, and Ag+. Chalcogenide glass also has selectivity for double-charged metal ions, such as Pb2+, and Cd2+.
- The glass membrane has excellent chemical durability and can work in very aggressive media.
- A very common example of this type of electrode is the pH glass electrode.

Crystalline membranes:

- Crystalline membranes are made from mono- or polycrystalline of a single substance.
- They have good selectivity, because only ions which can introduce themselves into the crystal structure can interfere with the electrode response.
- This is the major difference between this type of electrodes and the glass membrane electrodes.
- The lack of internal solution reduces the potential junctions.
- Selectivity of crystalline membranes can be for both cation and anion of the membrane-forming substance.
- An example is the fluoride selective electrode based on LaF_3 crystals.

Ion-exchange resin membranes:

- Ion exchange resin are based on special organic polymer membranes which contain a specific ion-exchange substance (resin).
- This is the most widespread type of ion-specific electrode.
- Usage of specific resins allows preparation of selective electrodes for tens of different ions, both single-atom or multi-atom.
- They are also the most widespread electrodes with anionic selectivity.
- However, such electrodes have low chemical and physical durability as well as "survival time".
- An example is the potassium selective electrode, based on valinomycin as an ion-exchange agent.

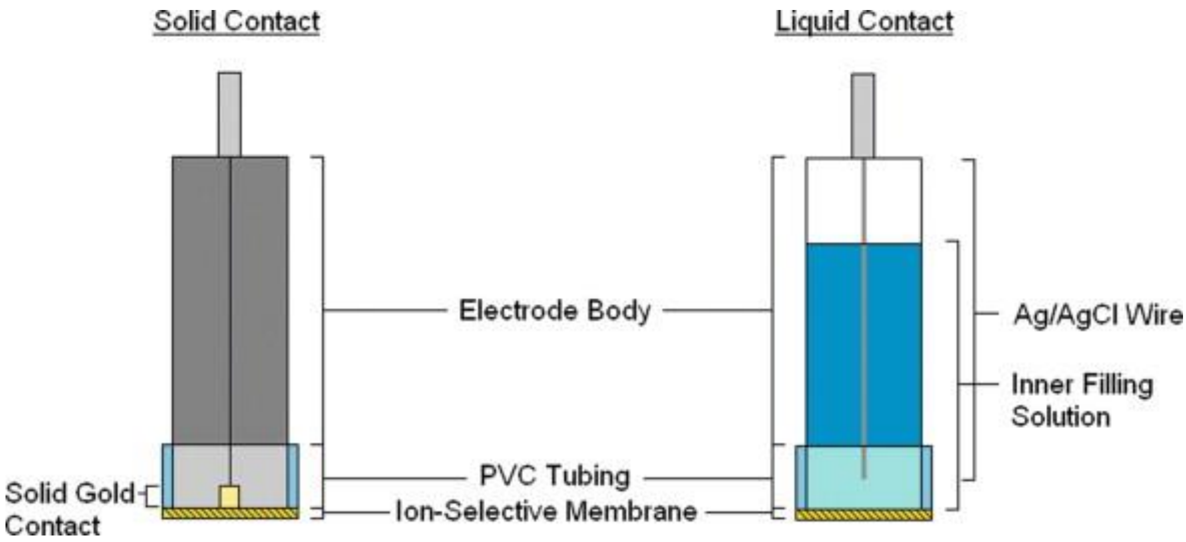
Enzyme electrodes:

- Enzyme electrodes definitely are not true ion-selective electrodes but usually are considered within the ion-specific electrode topic.
- Such an electrode has a "double reaction" mechanism - an enzyme reacts with a specific substance, and the product of this reaction (usually H^+ or OH^-) is detected by a true ion-selective electrode, such as a pH-selective electrodes.
- All these reactions occur inside a special membrane which covers the true ion-selective electrode, which is why enzyme electrodes sometimes are considered as ion-selective. An example is glucose selective electrodes.

WORKING:

- The ion selective electrode works based on the principle of a galvanic cell.
- It consists of reference electrode, ion selective membrane and voltmeter.

- The transport of ions from an area of high concentration to low concentration through the selective binding of ions with specific sites of the membranes creates a potential difference.
- This potential is measured with respect to a stable reference electrode having a constant potential and net charge is determined.
- The difference is potential between the electrode and the membrane depends on the activity of the specific ion in solution.



- The strength of the net charge that measured is directly proportional to the concentration of the selected ion.
- The electric potential can be calibrated by direct means, standard additions and titrations.
- However, direct calibrations are the most common means of measuring conditions.

APPLICATIONS:

Some of the major applications of ion selective electrode include the following:

- Analysis of environmental samples.
- Groundwater monitoring.
- Fluoride detection around aluminium mills.
- Biomedical laboratories.

3. With suitable diagram, explain about the measurement of pH and PCO2. (MAY 2019, NOV 2015)

Measurement of pH:

- pH (denoting 'potential of hydrogen' or 'power of hydrogen') is a scale used to specify the acidity or basicity of an aqueous solution.
- Acidic solutions (solutions with higher concentrations of H+ ions) are measured to have lower pH values than basic or alkaline solutions.
- The pH scale is logarithmic and inversely indicates the concentration of hydrogen ions in the solution.
- This is because the formula used to calculate pH approximates the negative of the base 10 logarithm of the molar concentration of hydrogen ions in the solution.
- More precisely, pH is the negative of the base 10 logarithm of the activity of the H+ ion.
- At 25 °C, solutions with a pH less than 7 are acidic, and solutions with a pH greater than 7 are basic.
- Solutions with a pH of 7 at this temperature are neutral (e.g. pure water). The neutral value of the pH depends on the temperature, being lower than 7 if the temperature increases.
- The pH value can be less than 0 for very strong acids, or greater than 14 for very strong bases.
- The pH scale is traceable to a set of standard solutions whose pH is established by international agreement.
- Primary pH standard values are determined using a concentration cell with transference, by measuring the potential difference between a hydrogen electrode and a standard electrode such as the silver chloride electrode.
- pH is defined as the decimal logarithm of the reciprocal of the hydrogen ion activity, aH+, in a solution.
- This definition was adopted because ion-selective electrodes, which are used to measure pH, respond to activity.
- Ideally, electrode potential, E, follows the Nernst equation, which, for the hydrogen ion can be written as ,

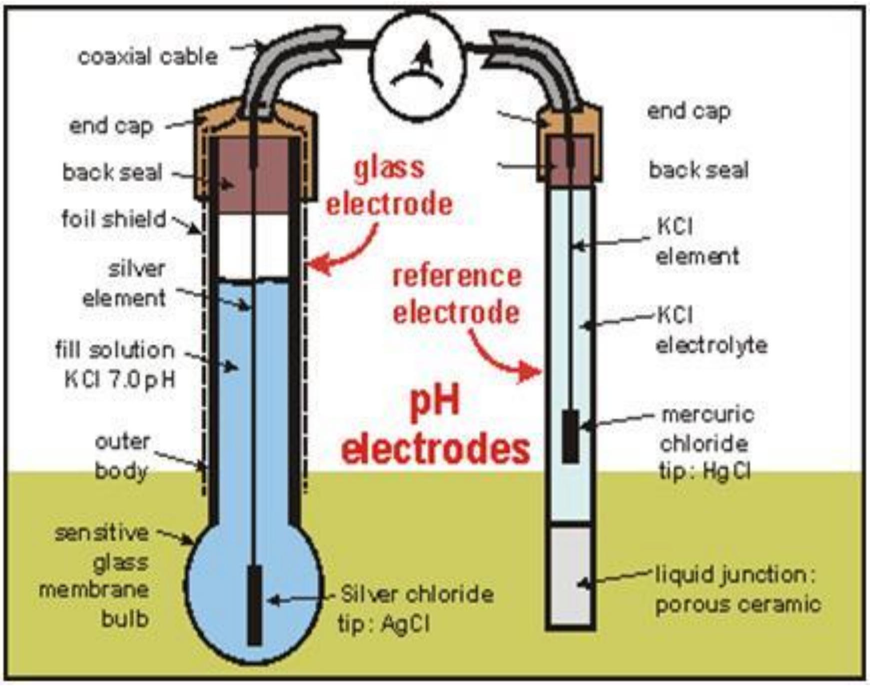
$$E = E^0 - \frac{RT}{zF} \ln Q$$

where, E is a measured potential,

E^0 is the standard electrode potential, R is the gas constant,

T is the temperature in Kelvin,

F is the Faraday constant.



pH Measurement:

- ❖ For making pH measurements, the solution is taken in a beaker.
- ❖ A pair of electrodes: one glass or indicating electrode and the other reference or calomel electrode, are immersed in the solution.
- ❖ The voltage developed across the electrodes is applied to an electronic amplifier, which transmits the amplified signal to the display.
- ❖ The pH meter is usually equipped with controls for calibration and temperature compensation.
- ❖ The glass electrode exhibits a high electrical resistance, of the order of' 100–1000 MW. The emf measurement, therefore, necessitates the use of measuring circuits with high input impedance.
- ❖ Further, the high resistance of glass electrodes render them highly susceptible to capacitive pickup from ac mains.
- ❖ In order to minimize such effects, it is advisable to screen the electrode cable. The screen is usually grounded to the case of the measuring instrument.

MEASUREMENT OF PCO2:

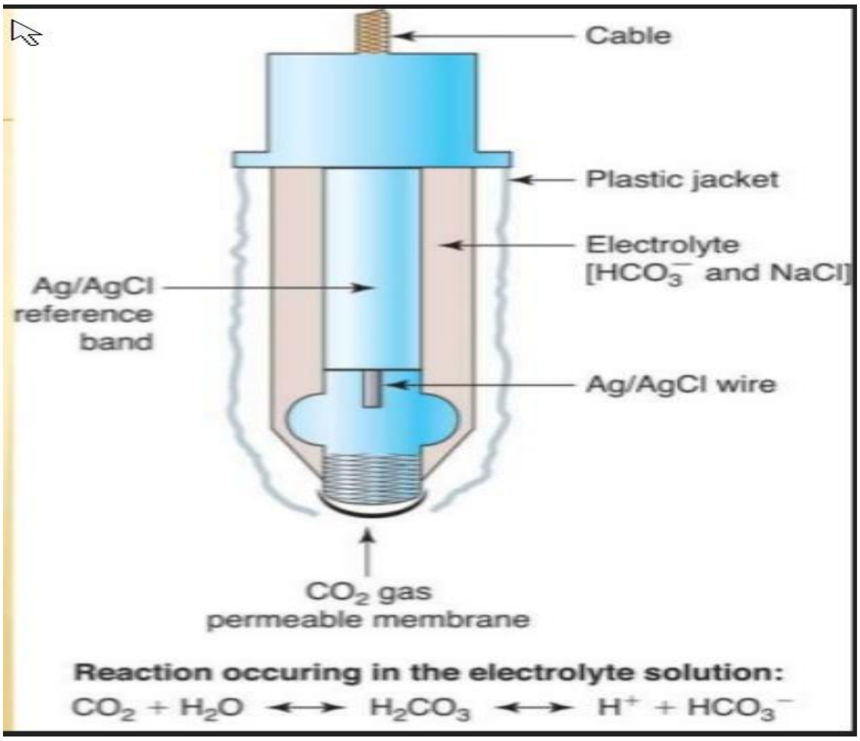
Partial pressure of carbon dioxide (PCO_2), often used in reference to blood but also used in meteorology, climate science, oceanography, and limnology to describe the fractional pressure of CO_2 as a function of its concentration in gas or dissolved phases.

$$PCO_2 = \text{Barometric pressure - water vapour pressure } (\%CO_2 / 100)$$

- PCO_2 electrode consists of ph sensitive glass electrode having a rubber membrane over it. All modern blood gas analysers make use of a PCO_2 electrode of the type described by Stow et al (1957).
- It basically consists of a pH sensitive glass electrode having a rubber membrane stretched over it, with a thin layer of water separating the membrane from the electrode surface.
- The technique is based on the fact that the dissolved CO_2 changes the pH of an aqueous solution.
- PCO_2 electrode is first described by stow et al at 1957.
- A thin layer of water separating the membrane from the electrode surface. The rubber membrane was also replaced by a thin Teflon membrane, which is permeable to CO_2 but not to any other ions, which might alter the pH of the bicarbonate solution.
- The $CO_2$from the blood diffuses into the bicarbonate solution. There will be a drop in pH due to CO_2 reacting with water forming carbonic acid.
- The pH falls by almost one pH unit for a ten-fold increase in the CO_2 tension of the sample. Hence, the pH change is a linear function of the logarithm of the CO_2tension.
- The optimum sensitivity in terms of pH change for a given change in CO_2 tension is obtained by using a bicarbonate solution of concentration of about 0.01 mole. The electrode is calibrated with the known concentration of CO_2.
- The response time of the CO_2 electrode is of the order of 0.5 to 3 min. This electrode was twice as sensitive and drifted much less than the Stow's electrode. Rubber membrane is permeable to co2 ions, which causes to change in ph value.
- The CO_2 from the blood defuses through the membrane to form H2CO3 which dissociates into H+ and HCO3. Thus the resultant change in ph is proportional to CO2 concentration. It won't provide required stability and sensitivity.

- Reyer (1967) constructed a PCO_2 electrode using 0.5 mm of polyethylene as a membrane and no separator between the glass surface and the surface.
- The added carbonic an hydrase to the electrolyte response time was found to be 6sec. The basic construction of electrode was modified by Bradly in 1958. In this construction water vapour, is replaced by thin film of an aqueous sodium bicarbonate (NAHCO3) solution.
- The rubber membrane was also replaced with Teflon membrane. Teflon is permeable to only CO2 ions. Hence the CO2 diffuse from the blood through the membrane so it will alter the ph value due to the CO2 with the water to form the carbonic acid. So the ph changes is a linear function of CO2 tension.
- The units of pCO2 are mmHg, atm, Pa, or any other standard unit of atmospheric pressure.
- The pCO2 of Earth's atmosphere has risen from approximately 280 ppm (parts-per-million) to a mean 2019 value of 409.8 ppm as a result of anthropogenic release of carbon dioxide from fossil fuel burning.
- This is the highest atmospheric concentration to have existed on Earth for at least the last 800,000 years.

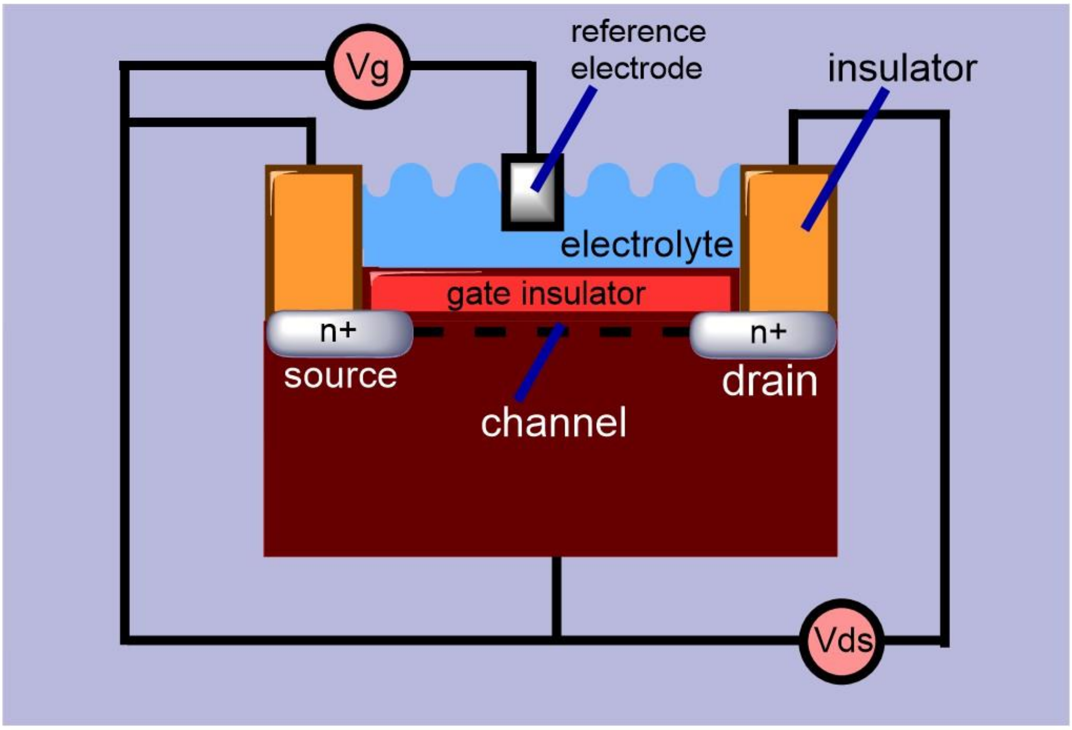
Measurement of PCO_2 in routine blood gases:



- A modified pH electrode with a CO_2 permeable membrane covering the glass membrane surface.
- A bicarbonate buffer separates the membranes.
- A change in pH is proportional to the concentration of dissolved CO_2 in the blood.

4. Explain how ISFET is used for the measurement of glucose and urea. (NOV 2018, MAY 2018, NOV 2017, MAY 2017, MAY 2016, MAY 2015)

- An ion-sensitive field-effect transistor (ISFET) is a field-effect transistor used for measuring ion concentrations in solution.
- When the ion concentration (such as H+, see pH scale) changes, the current through the transistor will change accordingly.
- Here, the solution is used as the gate electrode. A voltage between substrate and oxide surfaces arises due to an ion sheath.
- It is a special type of MOSFET (metal-oxide-semiconductor field-effect transistor), and shares the same basic structure, but with the metal gate replaced by an ion-sensitive membrane, electrolyte solution and reference electrode.



- **The schematic view of an ISFET.** Source and drain are the two electrodes used in a FET.
- The electron flow takes place in a channel between the drain and source. The gate potential controls the flow of current between the two electrodes.
- The surface hydrolysis of Si–OH groups of the gate materials varies in aqueous solutions due to pH value.
- Typical gate materials are SiO2, Si3N4, Al2O3 and Ta2O5.
- The mechanism responsible for the oxide surface charge can be described by the site binding model, which describes the equilibrium between the Si–OH surface sites and the H+ ions in the solution.
- The hydroxyl groups coating an oxide surface such as that of SiO_2 can donate or accept a proton and thus behave in an amphoteric way as illustrated by the following acid-base reactions occurring at the oxide-electrolyte interface:

$$—Si–OH + H_2O \leftrightarrow —Si–O^- + H_3O^+$$

$$—Si–OH + H_3O^+ \leftrightarrow —Si–OH_2^+ + H_2O$$

- An ISFET's source and drain are constructed as for a MOSFET.
- The gate electrode is separated from the channel by a barrier which is sensitive to hydrogen ions and a gap to allow the substance under test to come in contact with the sensitive barrier.
- An ISFET's threshold voltage depends on the pH of the substance in contact with its ion-sensitive barrier. An ISFET electrode sensitive to H+ concentration can be used as a conventional glass electrode to measure the pH of a solution. However, it also requires a reference electrode to operate.
- If the reference electrode used in contact with the solution is of the Agcl or Hg2Cl2 classical type, it will suffer the same limitations as conventional pH electrodes (junction potential, KCl leak, and glycerol leak in case of gel electrode). A conventional reference electrode can also be bulky and fragile.
- A too large volume constrained by a classical reference electrode also precludes the miniaturization of the ISFET electrode, a mandatory feature for some biological or in vivo clinical analyses (disposable mini-catheter pH probe).

- The breakdown of a conventional reference electrode could also make problem in on-line measurements in the pharmaceutical or food industry if highly valuable products are contaminated by electrode debris or toxic chemical compounds at a late production stage and must be discarded for the sake of safety.
- For ISFET-based sensors, low-frequency noise is most detrimental to the overall SNR as it can interfere with biomedical signals which span in the same frequency domain.
- The noise has mainly three sources.
- The noise sources outside the ISFET itself are referred to as the external noise, such as environmental interference and instrument noise from terminal read-out circuits.

ISFET for glucose:

- It is an electronic device that has developed to measure pH and other ions. Ions sensitivity is depending on physiochemical properties of membrane.
- ISFET glucose sense determines the quantity of glucose by measuring the ph variation.
- Change in pH is due to dissociation of gluconic acid generated by enzyme reaction and electrolysis of hydrogen peroxide. The hydrogen ion is generated by the enzyme immobilized membranes.
- These hydrogen ions delay the recovery time due to chemical reaction to equilibrium the concentrations inside and outside the membrane. By electrolysis procedure -0.7v reduction potential is applied to plantium. Silver- silver chloride electrode is act as reference electrode.
- Reduction potential is used to improve recovery time by generating OH+ ions with combination of $O_2+2H_2O+4e^-$. The generated hydroxyl ion reduces the recovery time.
- The sensor output signal is converted into voltage signal using null balance circuit (Bridge circuit voltage).
- The threshold voltage of ISFET is stabilized by inner feedback loop using DAC. The 0.7 v at platinum is used for enhancing the sensitivity for oxidation.
- The recovery time were measured by double electrode structure. Ag \Agcl is used as reference electrode that provides proper gate voltage.

5. Mention about the construction and working of transcutaneous PO_2 electrodes. (NOV 2018, MAY 2018, NOV 2016, MAY 2016)

- The partial pressure of oxygen in the blood or plasma indicates the extent of oxygen exchange between the lungs and the blood, and normally, the ability of the blood to adequately perfuse the body tissues with oxygen.
- Partial pressure of oxygen is usually measured with a polarographic electrode.
- There is a characteristic polarizing voltage at which any element in solution is predominantly reduced and in the case of oxygen, it is 0.6 to 0.9 V.
- In this voltage range, it is observed that the current flowing in the electrochemical cell is proportional to the oxygen concentration in the solution.
- Most of the modern blood gas analysers utilize an oxygen electrode first described by Clark (1956) for measuring oxygen partial pressure.
- This type of electrode consists of a platinum cathode, a silver/silver chloride anode in an electrolyte filling solution and a polypropylene membrane.
- The electrode is of a single unit construction and contains the reference electrode also in its assembly. The entire unit is separated from the solution under measurement by the polypropylene membrane.
- Oxygen from the blood diffuses across the membrane into the electrolyte filling solution and is reduced at the cathode.
- The circuit is completed at the anode, where silver is oxidized, and the magnitude of the resulting current indicates the partial pressure of oxygen. The reactions occurring at the anode and cathode are:

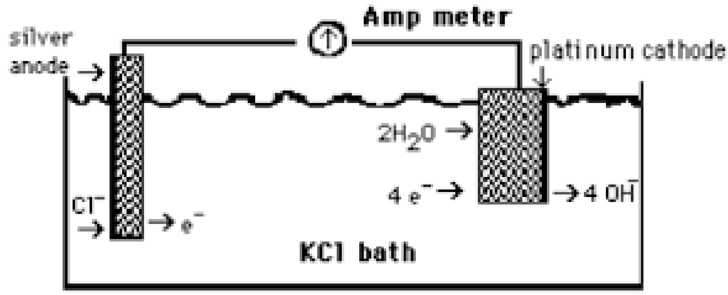
  Cathode reaction: $O_2 + 2H_2O + 4e^- = 4OH^-$

  Anode reaction: $4Ag = 4Ag^+ + 4e^-$

- The Clark electrode for measuring pO2 has been extensively studied and utilized. It is found to be of particular advantage for measuring blood samples.
- The principal advantages are: (i) sample size required for the measurement can be extremely small, (ii) the current produced due to pO2 at the electrode is linearly related to the partial pressure of oxygen, (iii) the electrode can be made small enough

to measure oxygen concentration in highly localized areas, (iv) the response time is very low, so the measurements can be made in seconds.

- As compared to this, it takes a very long time if the measurements are made by chemical means. The platinum cathode of the oxygen electrode tends to become contaminated or dimensionally unstable with time and use. The result is usually an inability to calibrate and slope the electrode on any pO2 range.
- The polar graphic electrodes usually exhibit ageing effect by showing a slow reduction in current over a period of time, even though the oxygen tension in the test solution is maintained at a constant level.
- Therefore, it needs frequent calibration. This is probably associated with the material depositing itself on to the electrode surface.
- The effect due to ageing can possibly be avoided by covering the electrode with a protective film of polyethylene, but it has the undesirable effect of increasing the response time.
- The measurement of current developed at the pO2 electrode due to the partial pressure of oxygen presents special problems. The difficulty arises because of the extremely small size of the electrical signal.
- The sensitivity (current per torr of oxygen tension) is typically of the order of 20 pA per torr for most commercial instruments. It is further subject to a constant drift and is also not independent of the sample characteristics.
- Measurement of oxygen electrode current is made by using high input impedance, low noise and low current amplifiers. Field effect transistors usually form the input stage of the preamplifiers.



Measuring PO_2 (Clark electrode)

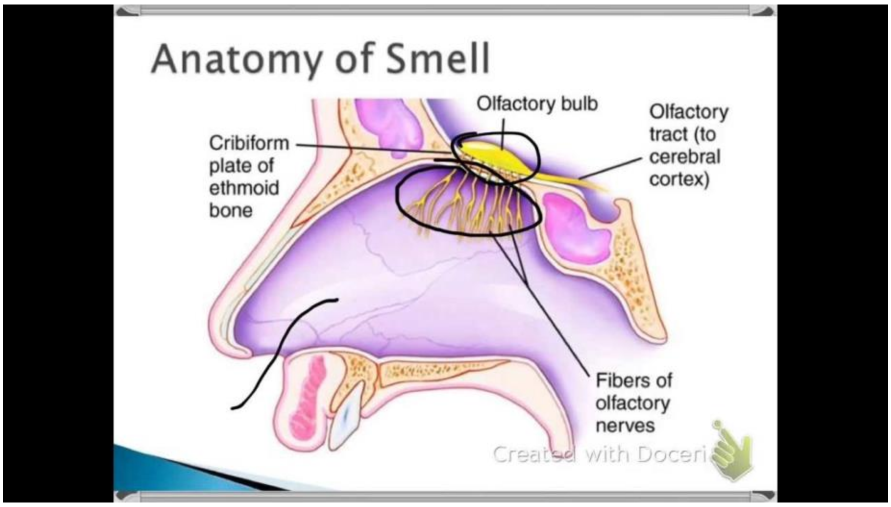
- McConn and Robinson (1963) observed that zero electrode current was not given by a solution having zero oxygen tension, but occurred at a definite oxygen tension, which they called the 'electrode constant'. So, for calibrating the electrode it was necessary to know this constant for that particular electrode.
- Further showed that when the straight line calibration curves were extended backwards, they did not pass through the origin, but intersected the oxygen tension axis at a negative value.
- To obtain a true zero-current (less than 10 nA), the electrolyte of the electrode is deoxygenated by bubbling nitrogen through it for about half an hour and then placing the electrode in water redistilled from alkaline pyragallol.
- Hahn (1969) used a field-effect transistor operational amplifier to measure small polar graphic currents. The op-amp is connected as a trans resistance converter, the output of which can be read directly by a digital voltmeter.
- The polarizing voltage is supplied by the cell B (1.3 V) and variable resistance VR1. The standing current from the electrochemical cell is cancelled by means of VR2, Battery B and 1 GW resistance.
- Capacitor C (100 pF) is included to limit the bandwidth of the amplifier to reduce noise and to ensure good dynamic stability.

6. Explain the sensors for smell, sound, vision, osmolality and taste. (NOV 2017)

<u>Sensor for smell:</u>

- Olfaction, or the sense of smell, is the special sense through which smells (or odors) are perceived.
- It occurs when an odor binds to a receptor within the nasal cavity, transmitting a signal through the olfactory system.
- Olfaction has many functions, including detecting hazards, and pheromones, and plays a role in taste.
- Glomeruli aggregate signals from these receptors and transmit them to the olfactory bulb, where the sensory input will start to interact with parts of the brain responsible for smell identification, memory, and emotion.

- There are many different causes for alteration, lack, or disturbance to normal olfaction, and can include damage to the peripheral nose or smell receptors, or central problems affecting the brain.
- Some causes include upper respiratory infections, traumatic brain injury, and neurodegenerative disease.
- In humans and other vertebrates, smells are sensed by olfactory sensory neurons in the olfactory epithelium.
- The olfactory epithelium is made up of at least six morphologically and biochemically different cell types.
- The proportion of olfactory epithelium compared to respiratory epithelium (not innervated, or supplied with nerves) gives an indication of the animal's olfactory sensitivity.
- The sensory olfactory system integrates with other senses to form the perception of flavour.



<u>Functions</u>:

Taste:

- Flavour perception is an aggregation of auditory, taste, haptic, and smell sensory information. Retronasal smell plays the biggest role in the sensation of flavour.
- During the process of mastication, the tongue manipulates food to release odorants. These odorants enter the nasal cavity during exhalation.

- ❖ The olfaction of food has the sensation of being in the mouth because of co-activation of the motor cortex and olfactory epithelium during mastication.
- ❖ Olfaction, taste, and trigeminal receptors (also called chemesthesis) together contribute to flavour.
- ❖ The human tongue can distinguish only among five distinct qualities of taste, while the nose can distinguish among hundreds of substances, even in minute quantities.
- ❖ It is during exhalation that the olfaction contribution to flavor occurs, in contrast to that of proper smell, which occurs during the inhalation phase of breathing.
- ❖ The olfactory system is the only human sense that bypasses the thalamus and connects directly to the forebrain.

Sensor for sound:

- ❖ Hearing or auditory perception is the ability to perceive sounds by detecting vibrations, changes in the pressure of the surrounding medium through time, through an organ such as the ear.
- ❖ The academic field concerned with hearing is auditory science. Sound may be heard through solid, liquid, or gaseous matter. It is one of the traditional five senses. Partial or total inability to hear is called hearing loss.
- ❖ In humans and other vertebrates, hearing is performed primarily by the auditory system: mechanical waves, known as vibrations, are detected by the ear and transduced into nerve impulses that are perceived by the brain (primarily in the temporal lobe).
- ❖ Like touch, audition requires sensitivity to the movement of molecules in the world outside the organism. Both hearing and touch are types of mechanosensation.

Hearing mechanism:

- ❖ The middle ear uses three tiny bones, the malleus, the incus, and the stapes, to convey vibrations from the eardrum to the inner ear.
- ❖ There are three main components of the human auditory system: the outer ear, the middle ear, and the inner ear.

Outer ear

- The outer ear includes the pinna, the visible part of the ear, as well as the ear canal, which terminates at the eardrum, also called the tympanic membrane.
- The pinna serves to focus sound waves through the ear canal toward the eardrum.
- Because of the asymmetrical character of the outer ear of most mammals, sound is filtered differently on its way into the ear depending on the location of its origin.
- This gives these animals the ability to localize sound vertically. The eardrum is an airtight membrane, and when sound waves arrive there, they cause it to vibrate following the waveform of the sound.
- Cerumen (ear wax) is produced by ceruminous and sebaceous glands in the skin of the human ear canal, protecting the ear canal and tympanic membrane from physical damage and microbial invasion.

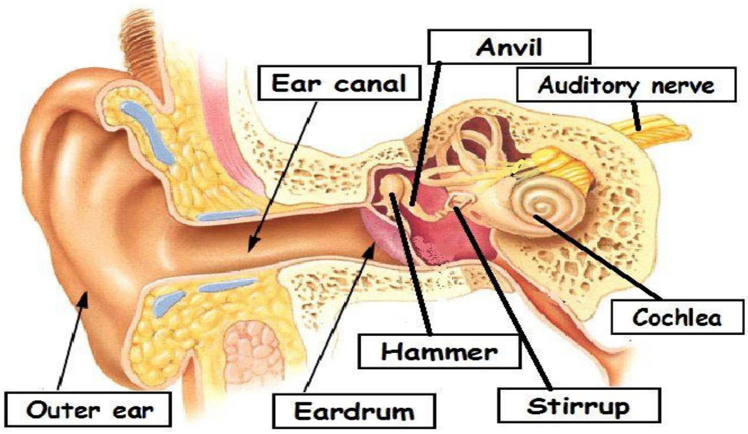
Middle ear

- The middle ear consists of a small air-filled chamber that is located medial to the eardrum.
- Within this chamber are the three smallest bones in the body, known collectively as the ossicles which include the malleus, incus, and stapes (alsoknown as the hammer, anvil, and stirrup, respectively).
- They aid in the transmission of the vibrations from the eardrum into the inner ear, the cochlea.
- The purpose of the middle ear ossicles is to overcome the impedance mismatch between air waves and cochlear waves, by providing impedance matching.
- Also located in the middle ear are the stapedius muscle and tensor tympani muscle, which protect the hearing mechanism through a stiffening reflex.
- The stapes transmits sound waves to the inner ear through the oval window, a flexible membrane separating the air-filled middle ear from the fluid-filled inner ear.
- The round window, another flexible membrane, allows for the smooth displacement of the inner ear fluid caused by the entering sound waves.

Inner ear

- The inner ear consists of the cochlea, which is a spiral-shaped, fluid-filled tube.

- It is divided lengthwise by the organ of Corti, which is the main organ of mechanical to neural transduction.
- Inside the organ of Corti is the basilar membrane, a structure that vibrates when waves from the middle ear propagate through the cochlear fluid – endolymph.
- The basilar membrane is tonotopic, so that each frequency has a characteristic place of resonance along it.
- Characteristic frequencies are high at the basal entrance to the cochlea, and low at the apex. Basilar membrane motion causes depolarization of the hair cells, specialized auditory receptors located within the organ of Corti.[
- While the hair cells do not produce action potentials themselves, they release neurotransmitter at synapses with the fibers of the auditory nerve, which does produce action potentials.
- In this way, the patterns of oscillations on the basilar membrane are converted to spatiotemporal patterns of firings which transmit information about the sound to the brainstem.



Hearing test:

- Hearing can be measured by behavioral tests using an audiometer.
- Electrophysiological tests of hearing can provide accurate measurements of hearing thresholds even in unconscious subjects.

- Such tests include auditory brainstem evoked potentials (ABR), otoacoustic emissions (OAE) and electrocochleography (ECochG). Technical advances in these tests have allowed hearing screening for infants to become widespread.

Hearing loss

There are several different types of hearing loss:

- Conductive hearing loss
- Sensorineural hearing loss
- Mixed hearing loss

Causes:

- Heredity
- Congenital conditions
- Presbycusis
- Acquired
- Noise-induced hearing loss
- Ototoxic drugs and chemicals
- Infection

Prevention:

- Hearing protection is the use of devices designed to prevent Noise-Induced Hearing Loss (NIHL), a type of post-lingual hearing impairment.
- The various means used to prevent hearing loss generally focus on reducing the levels of noise to which people are exposed.

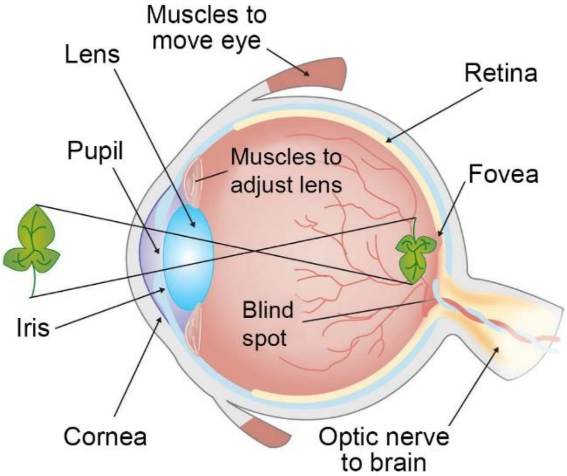
Sensors for vision:

- Visual perception is the ability to interpret the surrounding environment using light in the visible spectrum reflected by the objects in the environment.
- This is different from visual acuity, which refers to how clearly a person sees (for example "20/20 vision").
- A person can have problems with visual perceptual processing even if they have 20/20 vision.

- ❖ The resulting perception is also known as eyesight, sight, or vision (adjectival form: visual, optical, or ocular).
- ❖ The various physiological components involved in vision are referred to collectively as the visual system, and are the focus of much research in linguistics, psychology, cognitive science, neuroscience, and molecular biology, collectively referred to as vision science.

Visual system:

- ❖ In humans and a number of other mammals, light enters the eye through the cornea and is focused by the lens onto the retina, a light-sensitive membrane at the back of the eye.
- ❖ The retina serves as a transducer for the conversion of light into neuronal signals.
- ❖ This transduction is achieved by specialized photoreceptive cells of the retina, also known as the rods and cones, which detect the photons of light and respond by producing neural impulses.
- ❖ These signals are transmitted by the optic nerve, from the retina upstream to central ganglia in the brain.
- ❖ The lateral geniculate nucleus, which transmits the information to the visual cortex. Signals from the retina also travel directly from the retina to the superior colliculus.

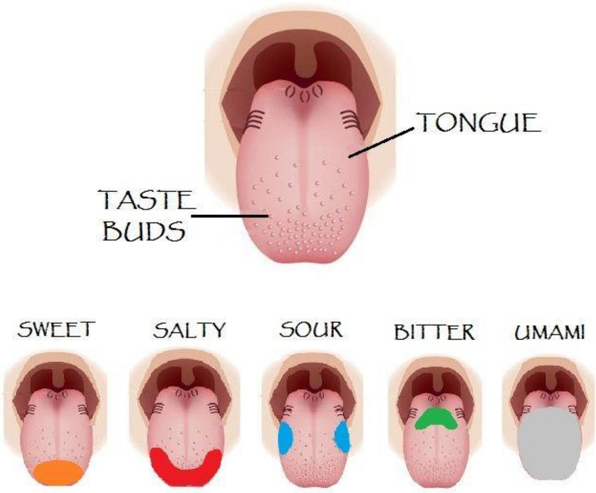


- ❖ The lateral geniculate nucleus sends signals to primary visual cortex, also called striate cortex. Extrastriate cortex, also called visual association cortex is a set of cortical structures, that receive information from striate cortex, as well as each other.

- Recent descriptions of visual association cortex describe a division into two functional pathways, a ventral and a dorsal pathway. This conjecture is known as the two streams hypothesis.

Sensors for taste:

- The gustatory system or sense of taste is the sensory system that is partially responsible for the perception of taste (flavor).
- Taste is the perception produced or stimulated when a substance in the mouth reacts chemically with taste receptor cells located on taste buds in the oral cavity, mostly on the tongue.
- Taste, along with olfaction and trigeminal nerve stimulation (registering texture, pain, and temperature), determines flavours of food and other substances.
- Humans have taste receptors on taste buds and other areas including the upper surface of the tongue and the epiglottis.
- The gustatory cortex is responsible for the perception of taste.
- The tongue is covered with thousands of small bumps called papillae, which are visible to the naked eye. Within each papilla are hundreds of taste buds.
- The exception to this is the filiform papillae that do not contain taste buds.
- There are between 2000 and 5000 taste buds that are located on the back and front of the tongue.
- Others are located on the roof, sides and back of the mouth, and in the throat.
- Each taste bud contains 50 to 100 taste receptor cells. Taste receptors in the mouth sense the five taste modalities: sweetness, sourness, saltiness, bitterness, and savoriness (also known as savory or umami)
- Sweetness, usually regarded as a pleasurable sensation, is produced by the presence of sugars and substances that mimic sugar. Sweetness may be connected to aldehydes and ketones, which contain a carbonyl group.
- Sweetness is detected by a variety of G protein coupled receptors (GPCR) coupled to the G protein gustducin found on the taste buds.



- Sourness is the taste that detects acidity.
- Sourness of substances is rated relative to dilute hydrochloric acid, which has a sourness index of 1. By comparison, tartaric acid has a sourness index of 0.7, citric acid an index of 0.46, and carbonic acid an index of 0.06.[23][24]
- Sour taste is detected by a small subset of cells that are distributed across all taste buds called Type III taste receptor cells.
- H+ ions (protons) that are abundant in sour substances can directly enter the Type III taste cells through a proton channel.[
- The simplest receptor found in the mouth is the sodium chloride (salt) receptor.
- Saltiness is a taste produced primarily by the presence of sodium ions. Other ions of the alkali metals group also taste salty, but the further from sodium, the less salty the sensation is.
- A sodium channel in the taste cell wall allows sodium cations to enter the cell.
- This on its own depolarizes the cell, and opens voltage-dependent calcium channels, flooding the cell with positive calcium ions and leading to neurotransmitter release.
- This sodium channel is known as an epithelial sodium channel (ENaC) and is composed of three subunits.
- Bitterness is one of the most sensitive of the tastes, and many perceive it as unpleasant, sharp, or disagreeable, but it is sometimes desirable and intentionally added via various bittering agents.

- Common bitter foods and beverages include coffee, unsweetened cocoa, South American mate, coca tea, bitter gourd, uncured olives, citrus peel, many plants in the family Brassicaceae, dandelion greens, horehound, wild chicory, and escarole.
- The ethanol in alcoholic beverages tastes bitter, as do the additional bitter ingredients found in some alcoholic beverages including hops in beer and gentian in bitters.
- Quinine is also known for its bitter taste and is found in tonic water.

Sensors for osmality:

Osmoreceptor:

- An Osmoreceptor is a sensory receptor primarily found in the hypothalamus of most homoeothermic organisms that detects changes in osmotic pressure.
- Osmoreceptor can be found in several structures, including two of the circumventricular organs – the vascular organ of the lamina terminalis, and the subcortical organ.
- They contribute to osmoregulation, controlling fluid balance in the body. Osmoreceptor are also found in the kidneys where they also modulate osmolality.

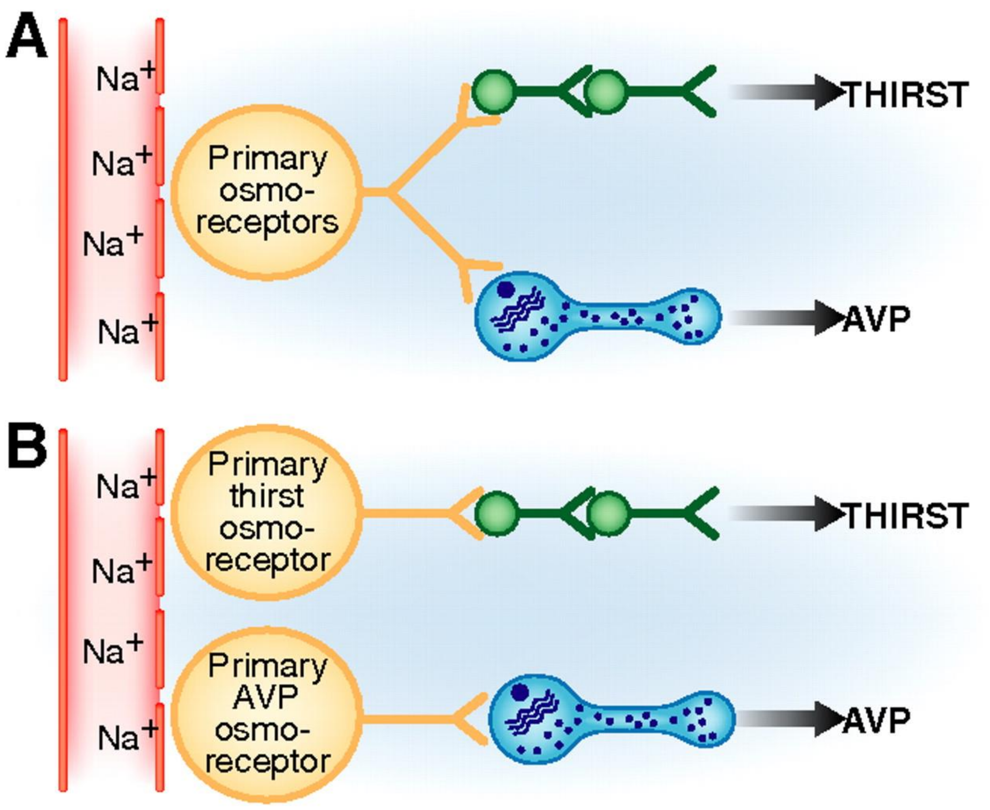
Mechanism of activation in humans:

- Osmoreceptor are located in the vascular organ of lamina terminalis (VOLT) a circumventricular organ which lacks a blood-brain barrier.
- They have a defined functionality as neurons that are endowed with the ability to detect extracellular fluid osmolality.
- The VOLT is strongly interconnected with the median preoptic nucleus, and together these structures comprise the anteroventral third ventricle region.
- Osmoreceptor have aquaporin 4 proteins spanning through their plasma membranes in which water can diffuse, from an area of high to low water concentration.
- If plasma osmolality rises above 290 mOsmol/kg, then water will move out of the cell due to osmosis, causing the neuroreceptor to shrink in size.
- Embedded into the cell membrane are stretch inactivated cation channels (SICs), which when the cell shrinks in size, open and allow positively charged ions, such as Na+ and K+ions to enter the cell.

- This causes initial depolarisation of the osmoreceptor and activates voltage-gated sodium channel, which through a complex conformational change, allows more sodium ions to enter the neuron, leading to further depolarisation and an action potential to be generated.
- This action potential travels along the axon of the neuron, and causes the opening of voltage-dependent calcium channels in the axon terminal.
- This leads to a Ca2+ influx, due to calcium ions diffusing into the neuron along theirr electrochemical gradient.
- The calcium ions binds to the synaptotagmin 1 sub-unit of the SNARE protein attached to the arginine-vasopressin (AVP) containing vesicle membrane.
- This causes the fusion of the vesicle with the neuronal post synaptic membrane. Subsequent release of AVP into the posterior pituitary gland occurs, whereby vasopressin is secreted into the blood stream of the nearby capillaries.

Macula densa:

- The macula densa region of the kidney's juxtaglomerular apparatus is another modulator of blood osmolality.
- The macula densa responds to changes in osmotic pressure through changes in the rate of sodium ion (Na+) flow through the nephron.
- Decreased Na+ flow stimulates tubuloglomerular feedback to auto regulate, a signal (thought to be regulated by adenosine) sent to the nearby juxtaglomerular cells of the afferent arteriole, causing the juxtaglomerular cells to release the protease renin into circulation.
- Renin cleaves the zymogen angiotensinogen, always present in plasma as a result of constitutive production in the liver, into a second inactive form, angiotensin I, which is then converted to its active form, angiotensin II, by angiotensin converting enzyme (ACE), which is widely distributed in the small vessels of the body, but particularly concentrated in the pulmonary capillaries of the lungs.
- Angiotensin II exerts system wide effects, triggering aldosterone releasefrom the adrenal cortex, direct vasoconstriction, and thirst behaviors originating in the hypothalamus.



- ❖ Three brain sensors regulate osmolality Certain regions of the brain, known as the circumventricular organs, lack a blood brain barrier.
- ❖ In a sense, they act as the brain's eyes and ears allowing it to quickly assess metabolic parameters and make necessary adjustments.
- ❖ In humans, two of these sensors are the subfornical organ (SFO) and the vascular organ of the lateral terminalis (OVLT), both located near the hypothalamus.
- ❖ These clusters of neurons contain specialized surface proteins called osmoreceptors capable of sensing changes in the concentration of sodium and chloride ions.
- ❖ If the blood becomes too concentrated (hyperosmolality), the SFO and OVLT activate hypothalamic neurons, ultimately culminating in the sensation of thirst.
- ❖ The third brain sensor is located in the hypothalamus and posterior pituitary gland.
- ❖ It consists of neurons whose cell bodies are located in the suproptic (SON) and paraventricular nuclei (PVN) of the hypothalamus but whose axon terminals extend into the posterior pituitary.
- ❖ These cells also contain osmoreceptors, but to some extent, they rely on hormonal signals from the kidney and adrenal glands to gauge osmolality.

7. Explain briefly about the working principle of Ion exchange membrane electrode. (MAY 2017, NOV 2016)

- An ion-exchange membrane is a semi-permeable membrane that transports certain dissolved ions, while blocking other ions or neutral molecules.
- Ion-exchange membranes are therefore electrically conductive.
- They are often used in desalination and chemical recovery applications, moving ions from one solution to another with little passage of water.
- Important examples of ion-exchange membranes include the proton-exchange membranes, that transport H+ cations, and the anion exchange membranes used in certain alkaline fuel cells to transport OH- anions.
- Ion selective electrodes, also known as ion electrodes, are electrodes that react to specific ions in an aqueous solution.
- Although a pH-sensitive glass electrode can be considered as a hydrogen ion electrode, it is generally not considered as an ion electrode.

Principle:

- Principle of ion-selective electrode (I.S.E.)
- An ideal I.S.E. consists of a thin membrane across which only the intended ion can be transported.
- The transport of ions from a high conc. to a low one through a selective binding with some sites within the membrane creates a potential difference.
- This is the most widespread type of ion-specific electrode.
- Usage of specific resins allows preparation of selective electrodes for tens of different ions, both single-atom or multi-atom.
- The metal cations (Na+) in the hydrated gel diffuse out of the glass and into solution while H+ from solution can diffuse into the hydrated gel.
- It is the hydrated gel, which makes the pH electrode an ion-selective electrode. ... All glass pH electrodes have extremely high electric resistance from 50 to 500 MΩ.
- The transfer of ions across biological membranes is central to physiological processes like nerve excitation, muscle cell contraction, and hormone secretion.

- This ability to select for specific ionic species is known as ion selectivity and is a fundamental property defining ion channel function.
- Ion-exchange resins are generally made from methacrylic acid, sulfonated styrene, and divinylbenzene (DVB).
- Ion exchange is a water treatment process commonly used for water softening or demineralization, but it also is used to remove other substances from the water in processes such as dealkalization, deionization, denitrification, and disinfection.

Types of ion selective membrane:

There are four main types of ion-selective membrane used in ion-selective electrodes (ISEs): glass, solid state, liquid based, and compound electrode.

Glass membranes:

- Glass membranes are made from an ion-exchange type of glass (silicate or chalcogenide).
- This type of ISE has good selectivity, but only for several single-charged cations; mainly H^+, Na^+, and Ag^+. Chalcogenide glass also has selectivity for double-charged metal ions, such as Pb^{2+}, and Cd^{2+}.
- The glass membrane has excellent chemical durability and can work in very aggressive media.
- A very common example of this type of electrode is the pH glass electrode.

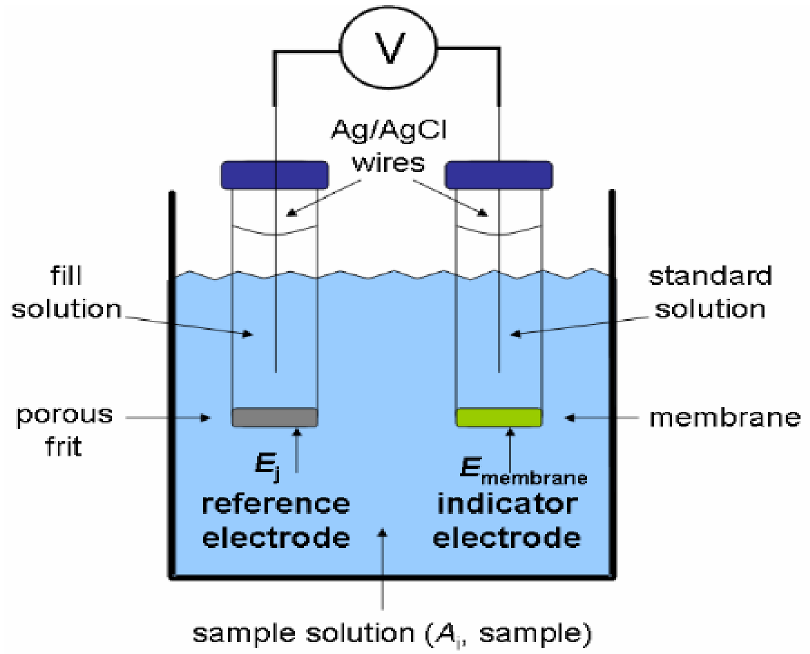
Crystalline membranes:

- Crystalline membranes are made from mono- or polycrystallites of a single substance.
- They have good selectivity, because only ions which can introduce themselves into the crystal structure can interfere with the electrode response.
- This is the major difference between this type of electrodes and the glass membrane electrodes.
- The lack of internal solution reduces the potential junctions.
- Selectivity of crystalline membranes can be for both cation and anion of the membrane-forming substance.
- An example is the fluoride selective electrode based on LaF_3 crystals.

Ion-exchange resin membranes:

- Ion-exchange resins are based on special organic polymer membranes which contain a specific ion-exchange substance (resin). This is the most widespread type of ion-specific electrode.
- Usage of specific resins allows preparation of selective electrodes for tens of different ions, both single-atom or multi-atom.
- They are also the most widespread electrodes with anionic selectivity. However, such
- Electrodes have low chemical and physical durability as well as "survival time". An example is the potassium selective electrode, based on valinomycin as an ion-exchange agent.

Enzyme electrodes:



- Enzyme electrodes definitely are not true ion-selective electrodes but usually are considered within the ion-specific electrode topic.
- Such an electrode has a "double reaction" mechanism - an enzyme reacts with a specific substance, and the product of this reaction (usually H+ or OH−) is detected by a true ion-selective electrode, such as a pH-selective electrodes.
- All these reactions occur inside a special membrane which covers the true ion-selective electrode, which is why enzyme electrodes sometimes are considered as ion-selective. An example is glucose selective electrodes.