Stream: ECE

Paper Name: Biomedical Electronics and Imaging

Paper Code: EC 704B Contacts: 3L Credits: 3 Total Contact: 36 Semester: 7th

Prepared by: Koushik Pal

Pre requisite:

(1) Concepts in Analog Electronics (Studied in Basic Electronics Engineering).
(2) Fundamental concepts on mathematics.
(3) Concepts in Digital signal Processing

Course Objectives:

- To familiarize the students with concepts related to medical electronics and imaging.
- To understand medical measurement systems and system modelling.
- To understand time domain and frequency domain analysis of real time biomedical signals like ECG,EEG etc.
- To understand the different medical imaging techniques like CT Scan, PET, ultrasound and understand the different types of data acquisition electrodes and amplifiers.

Module I: Introduction of Medical Electronics:

Origins of Bioelectric signals , Electrocardiogram (ECG),Electromyogram (EMG) ,Recording Electrodes- Silver-silver Electrodes ,Electrodes for ECG, EEG and EMG ,Physiological Transducers- Pressure Transducers, Temperature sensors, Pulse sensors; Sources of bioelectric potential, resting potential, action potential, propagation of action potentials in nerves, Rhythmic excitation of heart. [6L]

Module II: Medical Measurement systems :

Specifications of instruments, static & dynamic characteristics, classification of errors, statistical analysis. Introduction to reliability, accuracy, fidelity, speed of response, linearization of technique, data acquisition system. Detection of physiological parameters using impedance techniques: Impedance and current distribution, bipolar and tetra polar circuits, skin impedance, galvanic skin response measurement, total body impedance, cardiac output, neural activity, respiratory activity, impedance plethysmography - resistance and capacitance type. [8L]

Module III: Bio-amplifier and Bio-potential electrodes

Need for bio-amplifier -single ended bio-amplifier, differential bio-amplifier –right leg driven ECG amplifier. Band pass filtering, isolation amplifiers –transformer and optical isolation -isolated DC amplifier and AC carrier amplifier. Chopper amplifier. Power line interference. Origin of bio potential and its propagation. Electrode-electrolyte interface ,electrode–skin interface, half cell potential, impedance,

polarization effects of electrode Non polarizable electrodes. Types of electrodes -surface, needle and micro electrodes and their equivalent circuits. Recording problems -measurement with two electrodes.[8L]

Module IV: Medical Signal Processing

Biomedical signal origin & dynamics (ECG), Biomedical signal origin & dynamics(EEG, EMG etc.), Filtering for Removal of artifacts Statistical Preliminaries; Time domain filtering (Synchronized Averaging, Moving Average) Illustrations ofproblem with case studies Morphological Analysis of ECG Correlation coefficient The Minimum phase correspondent and Signal Length.[8L]

Module V :Medical Imaging Techniques

CT scan, ultrasound, NMR and PET ,Experiments are based on acquisition of biomedical signals, Implementation of algorithms covered in the course to characterize these signals. [6L]

Refere nce Books:

1. Wavelets and Time frequency methods for Biomedical signal Processing- M. Akay, IEEE Press,
2. Digital Processing of speech signals- L. Rabinar, Pearson Education
3. Biomedical Instrumentation and Measurements-Cromwell, Weibell and Pfeiffer, PHI

Course Outcome
EC704B

Biomedical Electronics and Imaging

EC704B.1	Explain Bioelectric signals ,human physiological system and different types of transducers.
EC704B.2	Understand different types of medical measurement system.
EC704B.3	Able to understand deferent types of biomedical signal acquisition electrodes and different types of signal amplification techniques and able to design the amplifiers .
EC704B.4	Able to examine the data handling ,filtering techniques of bio-medical signals and able to analysis of time and frequency domain.
EC704B.5	Able to understand medical imaging techniques and implement different algorithems to feature extract the signals.

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Mapping of POs with COs:

	PO 1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	P10	P11	P12
EC704B.1	3	3	2	-	**2**	**1**	**-**	**-**	**1**	**1**	**-**	**1**
EC704B.2	3	2	2	-	**-**	**-**	**-**	**-**	**2**	**1**	**-**	1
EC704B.3	3	2	1	2	**1**	**1**	**-**	**-**	**2**	**1**	**-**	-
EC704B.4	3	1	-	-	**1**	**1**	**-**	**-**	**2**	**1**	**-**	1
EC704B.5	1	1	3	2	**1**	**1**	**-**	**-**	**2**	**1**	**-**	1
EC704B avg												

Module1

Signal

A signal is a single-valued representation of information as a function of an independent variable (e.g., time). The specific type of information being represented may have real or complex values. A signal may be a function of another variable besides time or even a function of two or more variables.

Biomedical signals

Human body is made up of a number of systems like respiratory, cardiovascular, nervous system, etc. Each of these systems is made up of several subsystems that carry on many physiological processes. Each physiological process is associated with certain types of signals that reflect their nature and activities. These signals are referred as biomedical signals.

Different types of biomedical signals are (i) Biochemical like hormones, neurotransmitters;(ii) Electrical like potentials, currents; Mechanical like pressure, temperature. **Bioelectric signals**

Bioelectric signals are specific types of biomedical signals which are obtained by electrodes that record the variations in electrical potential generated by physiological processes.

Examples of bioelectric signals are electrocardiogram (ECG), electroencephalogram (EEG), electromyogram (EMG), electrooculogram (EOG).

Electrocardiogram (ECG)

ECG is the graphical recording of the electrical activity of the heart. It is the combination of many action potentials(APs) from different regions of the heart that makes up the ECG.

ECG consists of waveforms that represent the polarization, depolarization, and repolarization of the atria and ventricles of the heart.

The waveforms are labelled as:

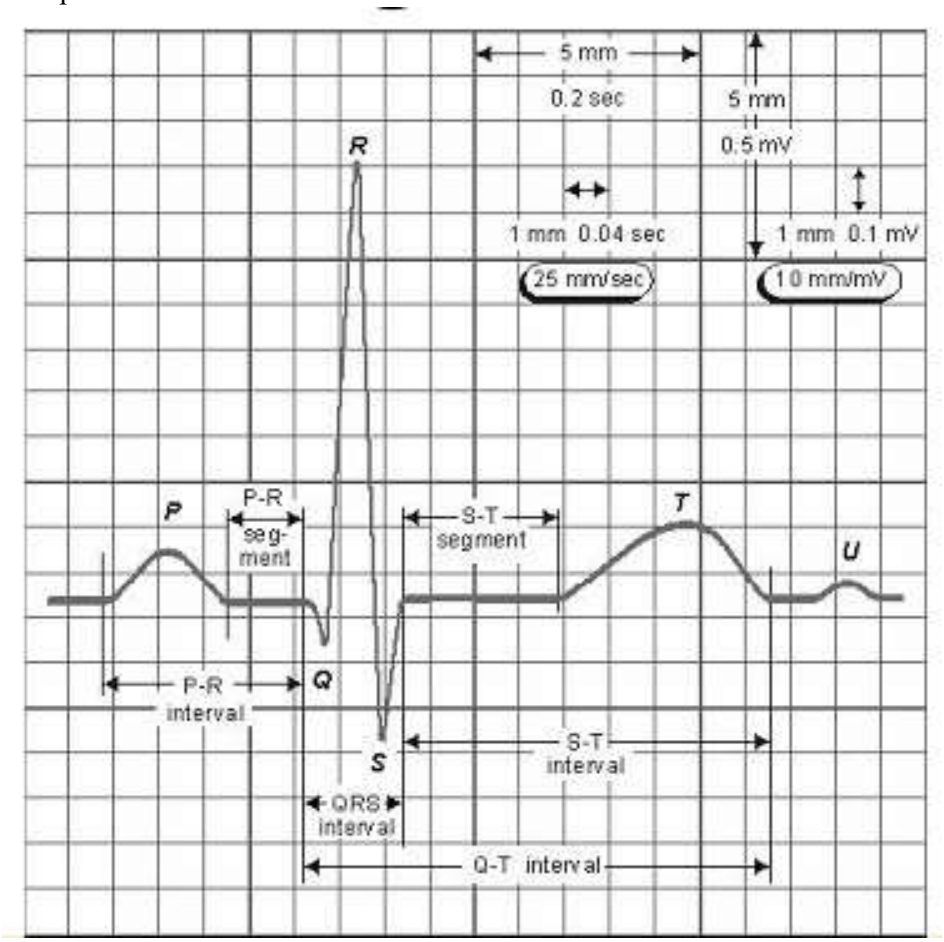
P wave: atrial depolarization

QRS complex: ventricular depolarization

T wave: ventricular repolarization

U wave: repolarization of the Purkinje fibers

Baseline: the polarized state



The Standard 12-Lead ECG

The ECG signal is recorded in three different electrode positions.

Standard Limb Leads I, II, III (Bipolar Limb Leads)

Unipolar limb leads (Augmented Limb Leads)

Unipolar chest leads. a. Standard Limb Leads – I, II, III

Each lead gives different reading. Twelve reading is obtained where 3 from the standard leads, 3 from the unipolar leads and 6 from the chest lead.

Bipolar Limb Leads: Standard Limb Leads I, II, III

- The electrode I, II and III is attached to the left arm, right arm and the leg. Each of these leads measures voltage between two points on the body.
- Lead I: Measure the voltage between the left arm and right arm in which the left arm is the positive pole. Most useful for seeing electrical activity moving in a horizontal direction.
- Lead II: connects the right arm to the leg, and therefore electricity moving down and leftward.
- Lead III: Measure the voltage potential between the left arm and the leg, thus monitor electricity moving down and rightward with the ECG regarded as the positive pole.
- The connection of these standard leads is known as the _Eithoven Triangle‖.

Unipolar Limb Leads

The same three leads that form the standard leads also form the three unipolar leads known as the augmented leads.

These three leads are referred to as aVR (right arm), aVL (left arm) and aVF (left leg) and also record a change in electrical potential in the frontal plane.

These leads are unipolar in that they measure the electric potential at one point with respect to a null point. This null point is obtained for each lead by adding the potential from the other two leads.

Unipolar Chest Leads (Precordial Leads)

For measuring the potentials close to the heart, Wilson introduced the precordial leads (chest leads) in 1944

These leads, V1-V6 are located over the left chest. The points V1 and V2 are located at the fourth intercostal space on the right and left side of the sternum .V4 is located in the fifth intercostals space at the midclavicular line .V3 is located between the points V2 and V4 .V5 is at the same horizontal level as V4 but on the anterior auxiliary line .V6 is at the same horizontal level as V4 but at the midline.

Characteristics of ECG

P Wave (with normal physiology and with the SA node acting as the pacemaker of the heart): The amplitude should not more than 3 mm tall. The peak of the P wave should be smooth and rounded. The P wave deflects in positive direction in 1, 11 and a VF leads .

PR Interval: Measure from the beginning of the P wave to the beginning of the QRS complex. The normal PR interval duration is 0.12 to 0.20 seconds or 120–200 ms.

QRS Complex: The wave of ventricular depolarization - QRS complex, even if not all of the components (the Q, the R, and the S) are present. Q wave: the first downward stroke. R wave: the first positive stroke S wave: a negative stroke that follows a positive upstroke. The QRS

should be at least 5 mm and not more than 20 mm tall. The width of the QRS is measured from the beginning of the Q wave to the end of the S. Normal QRS duration is 0.06 to 0.10 seconds, and does not exceed 0.12 seconds.

ST Segment : Begins at the J point (the point at which the QRS complex ends and the ST segment begins). The ST segment duration starts from the J point up to the beginning of the T wave. Indicate the period of time between the end of ventricular depolarization and the beginning of ventricular repolarization. Generally the ST segment is isoelectric, or on the baseline. A deviation of the ST segment from the baseline (either a depression or elevation) may be indicative of myocardial ischemia.

T Wave: The wave of ventricular repolarization. Usually deflects in the same direction as the QRS complex, and should be smooth and rounded. The period from the beginning of the T wave to nearly the end is called the ―relative refractory period‖. At this time, the ventricles are vulnerable. A stronger than normal stimulus could trigger depolarization. If an R wave (ventricular depolarization) should occur during this time, a potentially fatal arrhythmia could result.

The baseline (isoelectric line): The resting phase of the conduction cycle, or the polarized state The straight line on the ECG tracing, represent an absence of electrical activity. Important because the beginning of a waveform is marked by a departure (or movement away) from the baseline. The ending of a waveform is marked in terms of a return to the baseline. This is critical to understand because in order to be able to examine and measure a waveform, a clear understanding of where the waveform begins and ends is necessary. The baseline is the reference point for determining the beginning and end of a waveform.

Electromyography (EMG)

Electromyography (EMG) is a diagnostic procedure to assess the health of muscles and the nerve cells that control them (motor neurons). EMG results can reveal nerve dysfunction, muscle dysfunction or problems with nerve-to-muscle signal transmission.

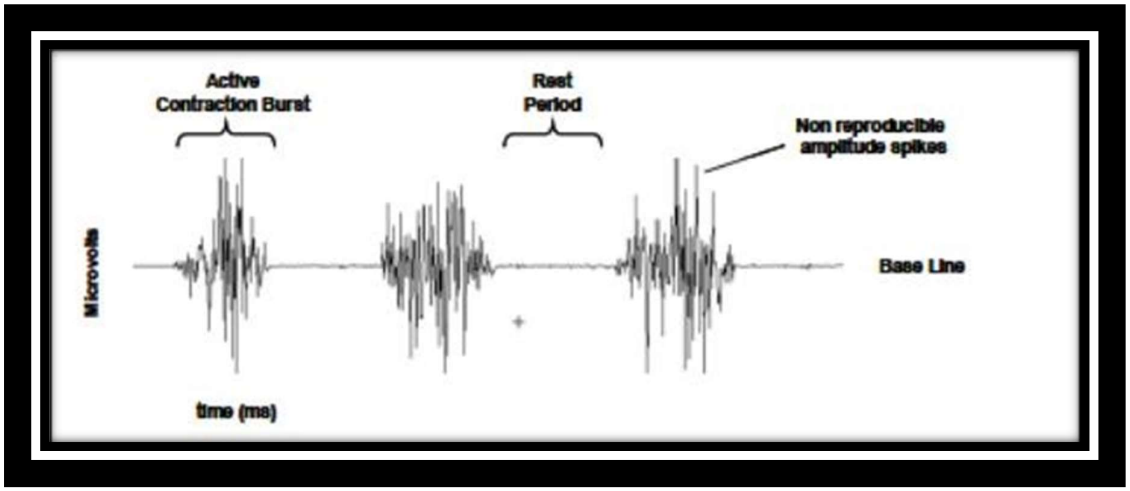
Motor neurons transmit electrical signals that cause muscles to contract. An EMG uses tiny devices called electrodes to translate these signals into graphs, sounds or numerical values that are then interpreted by a specialist.

During a needle EMG, a needle electrode inserted directly into a muscle records the electrical activity in that muscle.

A nerve conduction study, another part of an EMG, uses electrode stickers applied to the skin (surface electrodes) to measure the speed and strength of signals traveling between two or more points.

The EMG signal (as perceived from surface electrodes) is composed of many individual motor unit action potentials (MUAPs) . Each MUAP has its own unique firing profile . Muscular efforts usually require the activation of more than 1 motor unit . According to Henneman‘s size principle, to increase strength, you recruit increasingly large, rapidly firing motor units . The result is a curve summation that can be difficult to analyze and interpret.

Main Characteristics Of The EMG Signal



• Dynamic: repetitive activation is easy to see (clear bursts)

• Tonic: static activation is more difficult to see

• There is always some baseline noise (at least 1-2 microvolts)

• Typical amplitude: microvolts (up to a few thousands in athletes)

• Typical frequency: 20 – 150 Hz

EEG(Electroenencephalography)

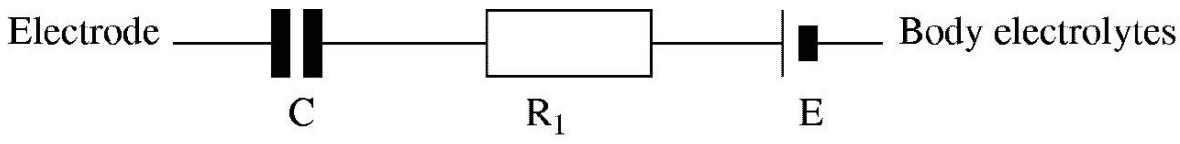
Electroenencephalography has found many clinical uses, from the investigation of epileptic fits to sleep (and vigilance) studies or the diagnosis of brain death. The EEG is the summation of neural depolarizations in the brain due to stimuli from the five senses as well as from normal

brain activity. On the surface of the brain, these potentials are of the order of 10 mV; the amplitude of the EEG signal recorded with scalp electrodes, however, is 100 μV, at most, because of the attenuation caused by the skull. EEG instrumentation is much more critical because of the lower amplitude of the EEG signal. The frequency response of EEG differential amplifiers usually extends from 0.1 to 100 Hz.

Characteristics of the EEG The frequency content of the EEG varies with the state of alertness and mental activity. To assist in EEG analysis, the normal EEG range of 0.5 to 30 Hz has been subdivided into five bands (note, however, that there is some degree of variation in the exact cut−offs from one system to another): Delta δ: 0.5 − 4 Hz ,Theta θ: 4 − 8 Hz ,Alpha α: 8 − 13 Hz, Beta β: 13 − 22 Hz, Gamma γ 22 − 30 Hz.

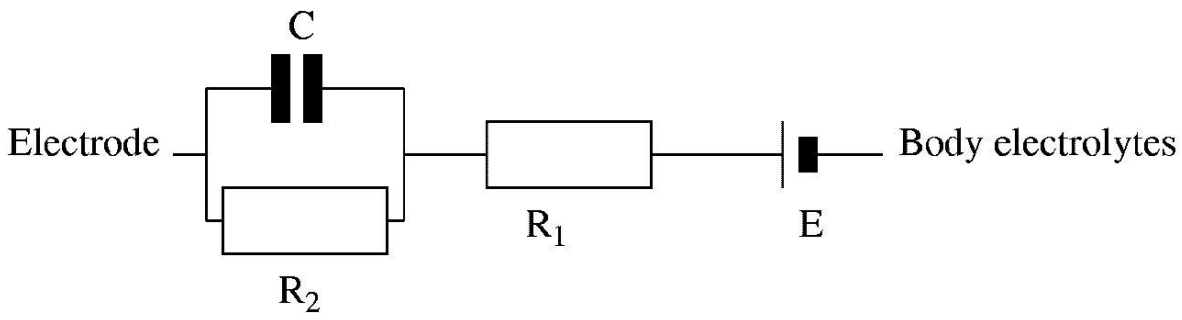
,Recording Electrodes- Silver-silver chloride electrode

Electrodes for recording biopotentials are composed of a metal (usually silver for ECG measurement), and a salt of the metal (usually silver chloride). In addition, some form of electrode paste or jelly is applied between the electrode (normally a flat silver disc) and the skin. The combination of the ionic electrode paste and the silver metal of the electrode forms a local solution of the metal in the paste at the electrode-skin interface (also referred to as the electrode-tissue interface or electrode-electrolyte interface). Hence, some of the silver dissolves into solution producing Ag+ ions: Ag Ag e Ionic equilibrium takes place when the electric field set up by the dissolving ions is balanced by the forces of the concentration gradient. At this point, there is a monomolecular layer of Ag+ ions at the surface of the electrode and a corresponding layer of Clions adjacent to this. This combination is called the electrode double layer and there is a potential drop E across this layer, called the half-cell potential (0.8V in the case of the Ag-AgCl electrode). Equivalent circuit of electrode interface The double layer of charges of opposite sign separated by a dielectric constitutes a form of capacitance, say C. However, since the Ag-AgCl electrode behaves mostly as a nonpolarisable electrode, the main component of the impedance is resistive, say R1.



Simple R-C model of electrode-electrolyte interface

The series model in above figure needs to be modified to account for the fact that the impedance does not increase to infinity as the frequency tends to zero. This is done by adding a parallel resistance *R*2 (as shown in below figure) which accounts for the electrochemical processes taking place at the electrode-electrolyte interface. The values of *R*1, *R*2 and *C* depend on the electrode area, surface condition, current density and the type and concentration of electrode paste used. (Typical values are *R*1 = 2k, *R*2 = 10k and *C* = 10F).



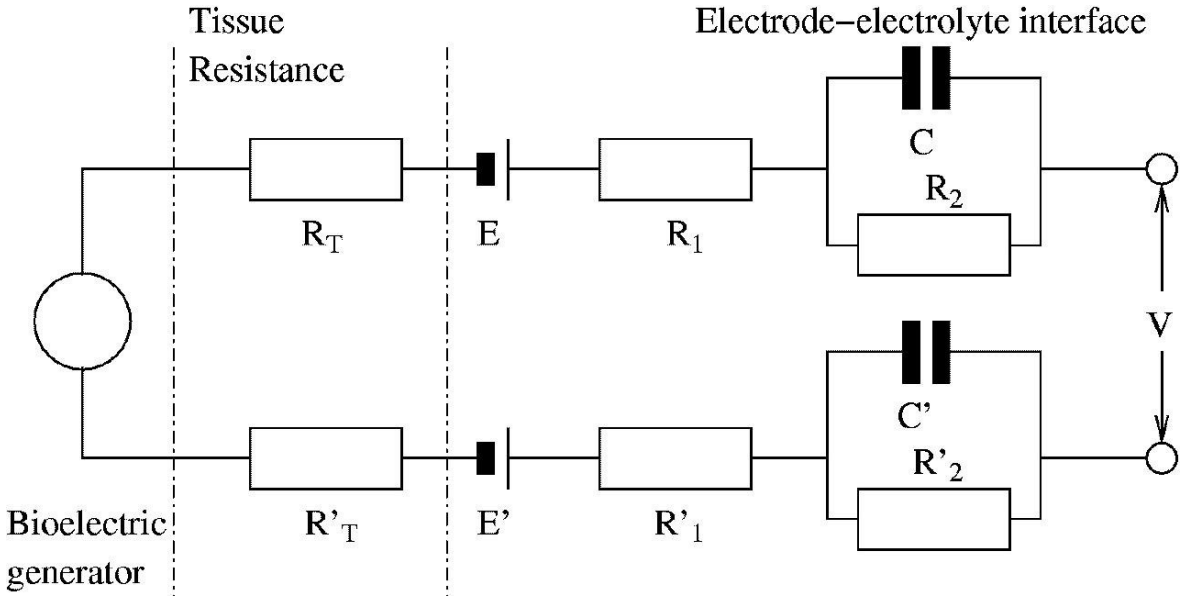
Equivalent circuit of the Ag-AgCl interface

Movement artefact

If the electrode is moved with respect to the electrolyte, this mechanically disturbs the distribution of charge at the interface and results in a momentary change of the half-cell potential until equilibrium can be re-established. If a pair of electrodes is in contact with an electrolyte and one of the electrodes moves while the other remains stationary, a potential difference appears between the two during this motion. This potential is referred to as *movement artefact* and can be a serious cause of interference in the measurement of the ECG (or any other biopotential). In addition to ECG measurements, biopotentials can also be recorded from the brain (electroencephalography − EEG) or from muscles (electromyography − EMG).

Overall equivalent circuit

If we represent the electrical activity of the heart by a voltage generator, model the tissues in the thorax as resistors and use the simple model of the electrode-electrolyte interface of Figure 4, we can put together an equivalent circuit which models the electrical impedance seen by the input stage of an ECG system. This overall equivalent circuit is shown in Figure below.

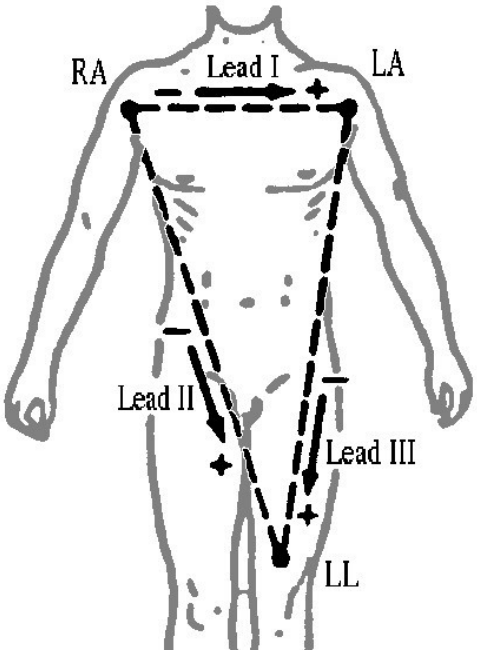


Equivalent circuit for tissue and electrode system

Although C and C', $R1$ and $R1'$, $R2$ and $R2'$ may not be exactly equal (different sites and modes of application on the skin), E should be equal to E' (same type of electrode). Hence V represents the actual difference of ionic potential between the two points on the body from which the ECG is being recorded.

ECG electrode

In order to record the ECG, we need a transducer capable of converting the ionic potentials generated within the body into electronic potentials which can be measured by conventional electronic instrumentation. Such a transducer consists of a pair of *electrodes*, which measure the ionic potential difference between their respective points of application on the body surface. Electrodes may be classified either as polarisable,
in which case they behave as capacitors, or non-polarisable, in which case they behave as resistors. Common electrodes have characteristics that lie between these extremes; the silversilver chloride electrode discussed above approximates more closely to a non-polarisable electrode.
If a pair of surface electrodes, attached to the left and right arms of a human subject, are connected to a high-input impedance differential amplifier, an electrical signal which varies in time with the heart beat will be observed at the output of the amplifier.



Typical electrode placement

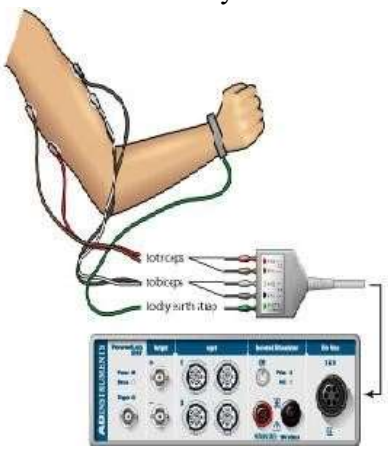
VI = (potential at LA) – (potential at RA)
VII = (potential at LL) – (potential at RA)
VIII = (potential at LL) – (potential at LA)

EEG electrodes

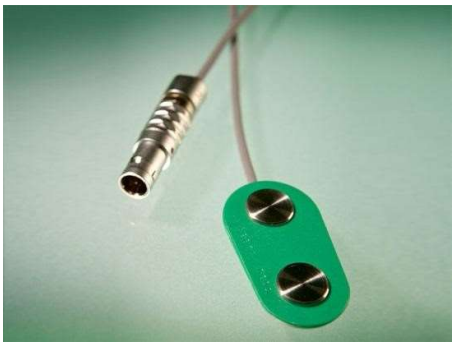
The EEG is measured with Ag−AgCl electrodes which are placed in standard positions on the skull, at regular intervals along three lines: one from the nose to the back of the head, one from ear to ear and one around the circumference of the skull.

EMG Electrodes

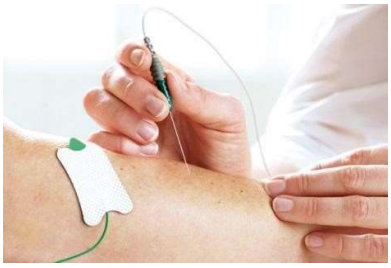
- Electrical potential difference measured between two points → bipolar electrode configuration used
- Bipolar Electrode Types
- Fine Wire
- Needle
- Surface
  - – Most common, less invasive
  - – Silver-silver chloride electrodes
- Electrode Placement
- Overlying the muscle of interest in the direction of predominant fiber direction
- Subject is GROUNDED by placing an electrode in an inactive region of body



Fine wire



Surface Electrodes



Needle electrode

Pressure Transducer

A pressure transducer, often called a pressure transmitter, is a transducer that converts pressure into an analog electrical signal. Although there are various types of pressure transducers, one of the most common is the strain-gage base transducer.

The conversion of pressure into an electrical signal is achieved by the physical deformation of strain gages which are bonded into the diaphragm of the pressure transducer and wired into a wheat stone bridge configuration. Pressure applied to the pressure transducer produces a deflection of the diaphragm which introduces strain to the gages. The strain will produce an electrical resistance change proportional to the pressure.
Pressure transducers are generally available with three types of electrical output; millivolt, amplified voltage and 4-20mA.

Millivolt Output Pressure Transducers

Transducers with millivolt output are normally the most economical pressure transducers. The output of the millivolt transducer is nominally around 30mV. The actual output is directly proportional to the pressure transducer input power or excitation.

If the excitation fluctuates, the output will change also. Because of this dependence on the excitation level, regulated power supplies are suggested for use with millivolt transducers. Because the output signal is so low, the transducer should not be located in an electrically noisy environment.

The distances between the transducer and the readout instrument should also be kept relatively short.

Voltage Output Pressure Transducers

Voltage output transducers include integral signal conditioning which provide a much higher output than a millivolt transducer. The output is normally 0-5Vdc or 0-10Vdc.

Although model specific, the output of the transducer is not normally a direct function of excitation. This means unregulated power supplies are often sufficient as long as they fall within a specified power range.

Because they have a higher level output these transducers are not as susceptible to electrical noise as millivolt transducers and can therefore be used in much more industrial environments.

4-20 mA Output Pressure Transducers

These types of transducers are also known as pressure transmitters. Since a 4-20mA signal is least affected by electrical noise and resistance in the signal wires, these transducers are best used when the signal must be transmitted long distances.

It is not uncommon to use these transducers in applications where the lead wire must be 1000 feet or more.

Types of Pressure Sensors

There are different types of pressure transducers based on their design. These sensors can come in several shapes and sizes, but the technology inside can also differ.

There 4 main types of pressure sensor based on this:

- Strain Gauge Pressure Transducers
- Capacitance Pressure Transducers
- Potentiometric Pressure Transducers
- Resonant Wire Pressure Transducers

Temperature Sensors

Temperature sensors are devices used to measure the temperature of a medium. There are 2 kinds on temperature sensors: 1) contact sensors and 2) noncontact sensors. However, the 3 main types are thermometers, resistance temperature detectors, and thermocouples. All three of these sensors measure a physical property (i.e. volume of a liquid, current through a wire), which changes as a function of temperature. In addition to the 3 main types of temperature sensors, there are numerous other temperature sensors available for use. Contact Sensors Contact temperature sensors measure the temperature of the object to which the sensor is in contact by assuming or knowing that the two (sensor and the object) are in thermal equilibrium, in other words, there is no heat flow between them. Examples

- Thermocouples
- Resistance Temperature Detectors (RTDs)
- Full System Thermometers
- Bimetallic Thermometers

Noncontact Sensors

Most commercial and scientific noncontact temperature sensors measure the thermal radiant power of the Infrared or Optical radiation received from a known or calculated area on its surface or volume within it. An example of noncontact temperature sensors is a pyrometer.

Thermometers

Thermometers are the most common temperature sensors encountered in simple, everyday measurements of temperature. Two examples of thermometers are the Filled System and Bimetal thermometers.

Filled System Thermometer

The familiar liquid thermometer consists of a liquid enclosed in a tube. The volume of the fluid changes as a function of temperature. Increased molecular movement with increasing temperature causes the fluid to expand and move along calibrated markings on the side of the tube. The fluid should have a relatively large thermal expansion coefficient so that small changes in temperature will result in detectable changes in volume. A common tube material is glass and a common fluid is alcohol. Mercury used to be a more common fluid until its toxicity was realized. Although the filled-system thermometer is the simplest and cheapest way to measure temperature, its accuracy is limited by the calibration marks along the tube length. Because filled system thermometers are read visually and don‘t produce electrical signals, it is difficult to implement them in process controls that rely heavily on electrical and computerized control.

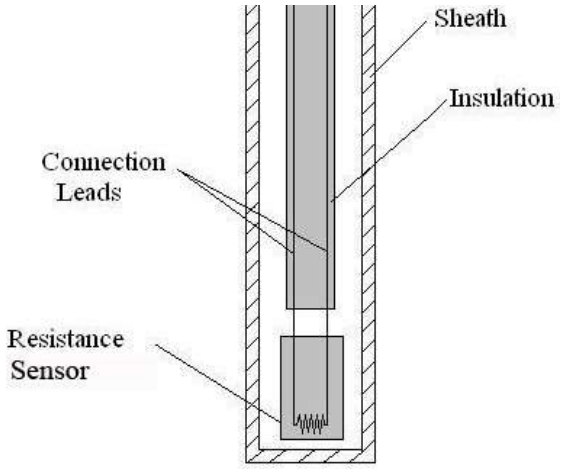
Bimetal Thermometer

In the bimetal thermometer, two metals (commonly steel and copper) with different thermal expansion coefficients are fixed to one another with rivets or by welding. As the temperature of the strip increases, the metal with the higher thermal expansion coefficients expands to a greater degree, causing stress in the materials and a deflection in the strip. The amount of this deflection is a function of temperature. The temperature ranges for which these thermometers can be used is limited by the range over which the metals have significantly different thermal expansion coefficients. Bimetallic strips are often wound into coils and placed in thermostats. The moving end of the strip is an electrical contact, which transmits the temperature thermostat.

Resistance Temperature Detectors

A second commonly used temperature sensor is the resistance temperature detector (RTD, also known as resistance thermometer). Unlike filled system thermometers, the RTD provides an electrical means of temperature measurement, thus making it more convenient for use with a computerized system. An RTD utilizes the relationship between electrical resistance and temperature, which may either be linear or nonlinear. RTDs are traditionally used for their high accuracy and precision. However, at high temperatures (above 700°C) they become very inaccurate due to degradation of the outer sheath, which contains the thermometer. Therefore, RTD usage is preferred at lower temperature ranges, where they are the most accurate. There are two main types of RTDs, the traditional RTD and the thermistor. Traditional RTDs use metallic sensing elements that result in a linear relationship between temperature and resistance. As the temperature of the metal increases, increased random molecular movement impedes the flow of electrons. The increased resistance is measured as a reduced current

through the metal for a fixed voltage applied. The thermistor uses a semiconductor sensor, which gives a power function relationship between temperature and resistance.



Schematic Diagram of Resistance Temperature Structure

the RTD contains an outer sheath to prevent contamination from the surrounding medium. Ideally, this sheath is composed of material that efficiently conducts heat to the resistor, but resists degradation from heat or the surrounding medium.

The resistance sensor itself is responsible for the temperature measurement, as shown in the diagram. Sensors are most commonly composed of metals, such as platinum, nickel, or copper. The material chosen for the sensor determines the range of temperatures in which the RTD could be used. For example, platinum sensors, the most common type of resistor, have a range of approximately -200°C – 800°C.

There are 4 major categories of RTD sensors. There are carbon resistors, film thermometers, wire-wound thermometers and coil elements.

Carbon resisters are the most commonly used. They are inexpensive and are accurate for low temperatures. They also are not affected by hysteresis or strain gauge effects. They are commonly used by researchers.

Film thermometers have a very thin layer of metal, often platinum, on a plate. This layer is very small, on the micrometer scale. These thermometers have different strain gauge effects based on what the metal and plate are composed of. There are also stability problems that are dependent on the components used.

In wire-wound thermometers the coil gives stability to the measurement. A larger diameter of the coil adds stability, but it also increases the amount the wire can expand which increases strain and drift. They have very good accuracy over a large temperature range.

Coil elements are similar to wire-wound thermometers and have generally replaced them in all industrial applications. The coil is allowed to expand over large temperature ranges while still giving support. This allows for a large temperature range while decreasing the drift.

Most traditional RTD operation is based upon a linear relationship between resistance and temperature, where the resistance increases with temperature. For this reason, most RTDs are made of platinum, which is linear over a greater range of temperatures and is resistant to corrosion. However, when determining a resistor material, factors such as temperature range, temperature sensitivity, response time, and durability should all be taken into consideration. Different materials have different ranges for each of these characteristics.

The principle behind RTDs is based upon the Callendar – Van Dusen equation shown below, which relates the electrical resistance to the temperature in °C. This equation is merely a generic polynomial that takes form based upon experimental data from the specific RTD. This equation usually takes on a linear form since the coefficients of the higher-order variables (*a*2, *a*3, etc.) are relatively small.

$$R_T = R_0(1 + a_1T + a_2T^2 + a_3T^3 + a_4T^4 + ... + a_nT^n)$$

R_T: Resistance at temperature T, in ohms R_0:
Resistance at temperature = 0°C, in ohms
a_n: Material's resistance constant, in $°C^{n-1}$.

Another type of RTD is the thermistor, which operates based upon an exponential relationship between electrical resistance and temperature. Thermistors are primarily composed of semiconductors, and are usually used as fuses, or current-limiting devices. Thermistors have high thermal sensitivity but low temperature measuring ranges and are extremely non-linear. Instead of the Calendar - Van Dusen equation, the thermistor operates based upon the nonlinear equation, shown in degrees K.

$$R_T = R_0 exp(b(\frac{1}{T} - \frac{1}{T_0}))$$

T_0: Initial temperature, usually set at 298K
b: Material's temperature coefficient of resistance, in K

Errors associated with resistance thermometers will occur due to the individual or collective efforts of: defective insulation, contamination of the resistor, or insecure lead wire connections.

Thermocouples

Another temperature sensor often used in industry is the thermocouple. Among the various temperature sensors available, the thermocouple is the most widely used sensor. Similar to the RTD, the thermocouple provides an electrical measurement of temperature.

Thermocouple Structure

The thermocouple has a long, slender, rod-like shape, which allows it to be conveniently placed in small, tight places that would otherwise be difficult to reach. the thermocouple contains an outer sheath, or thermowell. The thermowell protects the contents of the thermocouple from mechanical and chemical damage.
Within the thermowell lies two metal wires each consisting of different metals. Various combinations of materials are possible for these metal wires. Three common thermocouple material combinations used for moderate temperature measurements are the PlatinumRhodium, Iron-Constantan, and Chromel-Alumel metal alloys. The metal alloys chosen for a thermocouple is based upon the emf value of the alloy pair at a given temperature.

Thermocouple Operation

The main principle upon which the thermocouple function is based on is the difference in the conductivities of the two wire materials that the thermocouple is made of, at a given temperature. This conductivity difference increases at higher temperatures and conversely, the conductivity difference decreases at lower temperatures. This disparity results in the thermocouples being more efficient and useful at higher temperatures. Since the conductivity difference is small at lower temperatures and thus more difficult to detect, they are inefficient and highly unreliable at low temperatures.

The conductivity difference between the two wires, along with a temperature difference between the two junctions, creates an electrical current that flows through the thermocouple. The first junction point, which is the point at which the two wires are connected, is placed within the medium whose temperature is being measured. The second junction point is constantly held at a known reference temperature. When the temperature of the medium differs from the reference temperature, a current flows through the circuit. The strength of this current is based upon the temperature of the medium, the reference temperature, and the materials of the metal wires. Since the reference temperature and materials are known, the temperature of the medium can be determined from the current strength.

Error associated with the thermocouple occurs at lower temperatures due to the difficulty in detecting a difference in conductivities. Therefore, thermocouples are more commonly used at higher temperatures (above -125°C) because it is easier to detect differences in conductivities. Thermocouples are operable over a wide range of temperatures, from -200°C to 2320°C, which indicates its robustness and vast applications. Thermocouples operate over this wide range of temperatures, without needing a battery as a power source. It should be noted that, the wire insulation might wear out over time by heavy use, thus requiring periodical checks and maintenance to preserve the accuracy of the thermocouple.

To determine the temperature of the medium from the current strength, the emf or voltage values of the current and of the wire materials at the reference temperatures must be known. Often, the measured

temperature can be found by using standard thermocouple tables. However, these tables are often referenced at 0°C. To correct for this different reference temperature, equation below can be used to calculate the temperature from a given current.

$$\xi_{T_1,T_3} = \xi_{T_1,T_2} + \xi_{T_2,T_3}$$

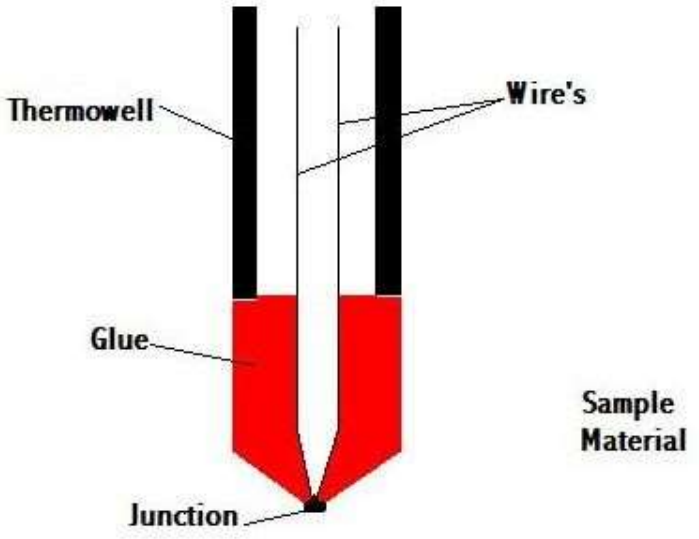
ξ: emf of an alloy combination generated at two different temperatures

$T1$: temperature of the medium whose temperature is to be determined

$T2$: reference temperature of the thermocouple

$T3$: reference temperature of the standard thermocouple table, which in this case is 0°C

Once the emf between two alloys is calculated relative to a reference temperature when T3 is 0°C, the standard thermocouple table can be used to determine the temperature T1 of the medium. This temperature is usually automatically displayed on the thermocouple.



Schematic diagram of how the thermocouple function

Laws of Thermocouple:

Law of homogenous material

If all the wires and the thermocouple are made of the same material, temperature changes in the wiring do not affect the output voltage. Thus, need different materials to adequately reflect the temperature.

Law of intermediate materials

o The sum of all the thermoelectric forces in a circuit with a number of dissimilar materials at a uniform temperature is zero. This implies that if a third material is added at the same temperature, no net voltage is generated by the new material.

Law of successive or intermediate temperatures

o If two dissimilar homogeneous materials produce thermal emf1 when the junctions are at T1 and T2 and produce thermal emf2 when the junctions are at T2 and T3 , the emf generated when the junctions are at T1 and T3 will be emf1 + emf2 .

Application :

Steel industry o Monitor temperature and chemistry throughout the steel making process.

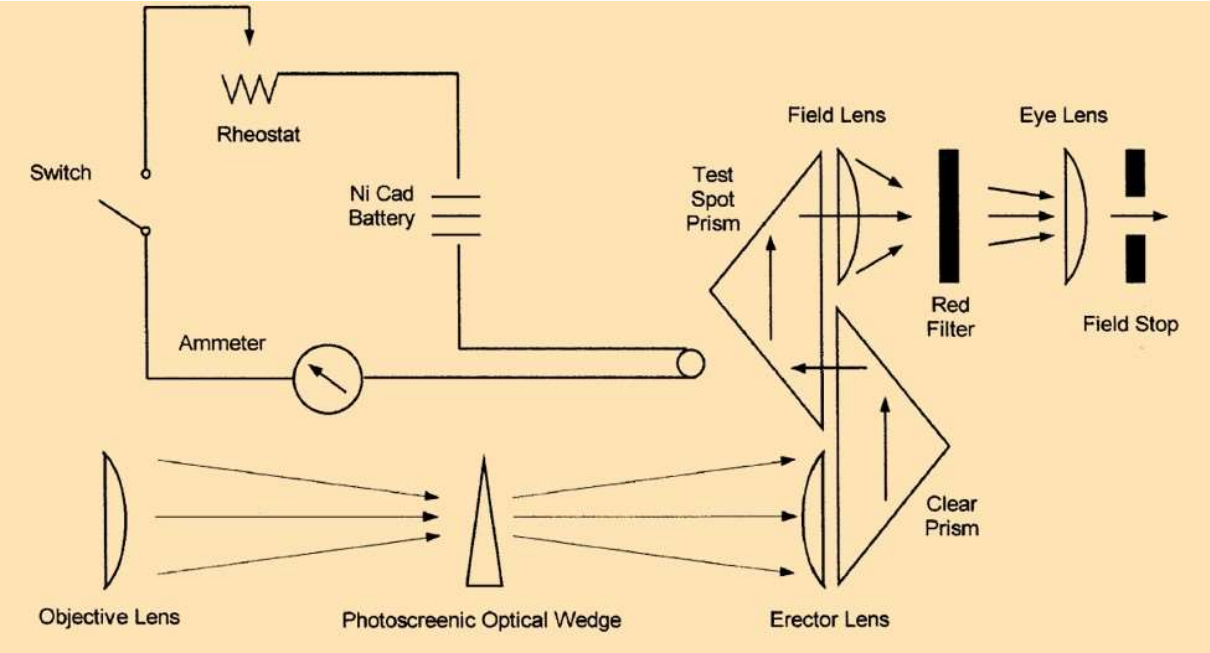
Heating appliance safety o Thermocouples in fail-safe mode are used in ovens and water heaters to detect if pilot flame is burning to prevent fire and health hazard.

Manufacturing o Used for testing prototype electrical and mechanical apparatus.

Process plants o Chemical production plants and refineries use computer programs to view the temperature at various locations. For this situation, a number of thermocouple leads are brought to a common reference block.

Pyrometers :

Unlike the thermometer, RTD and the thermocouple, pyrometers (non-contact temperature sensors) measures the amount of heat radiated, rather than the amount of heat conducted and convected to the sensor. Various types of pyrometers, such as total radiation and photoelectric pyrometers, exist. Below is a schematic of an optical pyrometer in Figure.



Schematic diagram of an optical pyrometer

These pyrometers differ in the type of radiation they measure. There are many factors that influence the amount of radiated heat detected, thus there are many assumptions that must be made regarding the emissivity, or the measure of the manner in which heat is radiated, of the object. These assumptions are based upon the manner in which heat is radiated as well as the geometry of the object. Because temperature is dependent on the emissivity of a body, these assumptions regarding the emissivity introduce uncertainties and inaccuracies in the temperature readings. Therefore, because of the error associated with them, pyrometers are not often used in industry.

Pulse sensors

Features

- Biometric Pulse Rate or Heart Rate detecting sensor
- Plug and Play type sensor
- Operating Voltage: +5V or +3.3V □ Current Consumption: 4mA
- Inbuilt Amplification and Noise cancellation circuit.
- Diameter: 0.625‖
- Thickness: 0.125‖ Thick

Warning

This sensor is not medical or FDA approved. It is purely intended for hobby projects/demos and should not be use for health critical applications.

Pin Configuration

Pin Number	Pin Name	Wire Colour	Description
1	Ground	Black	Connected to the ground of the system
2	Vcc	Red	Connect to +5V or +3.3V supply voltage
3	Signal	Purple	Pulsating output signal.

How Pulse sensor works

The working of the **Pulse/Heart beat sensor** is very simple. The sensor has two sides, on one side the LED is placed along with an ambient light sensor and on the other side we have some circuitry. This circuitry is responsible for the amplification and noise cancellation work. The LED on the front side of the sensor is placed over a vein in our human body. This can either be your Finger tip or you ear tips, but it should be placed directly on top of a vein.

Now the LED emits light which will fall on the vein directly. The veins will have blood flow inside them only when the heart is pumping, so if we monitor the flow of blood we can monitor the heart beats as well. If the flow of blood is detected then the ambient light sensor will pick

up more light since they will be reflect ted by the blood, this minor change in received light is analysed over time to determine our heart beats.

How to use Pulse sensor

Using the pulse sensor is straight forward, but positioning it in the right way matters. Since all the electronics on the sensor are directly exposed it is also recommended to cover the sensor with hot glue, vinyl tape or other non conductive materials. Also it is not recommended to handle these sensors with wet hands. The flat side of the sensor should be placed on top of the vein and a slight presser should be applied on top of it, normally clips or Velcro tapes are used to attain this pressure.

To use the sensor simply power it using the Vcc and ground pins, the sensor can operate both at +5V or 3.3V system. Once powered connect the Signal pin to the ADC pin of the microcontroller to monitor the change in output voltage.

Applications

- Sleep Tracking
- Anxiety monitoring
- Remote patient monitoring/alarm system
- Health bands
- Advanced gaming consoles

Sources of Bioelectric potentials

Bioelectricity, electric potentials and currents produced by or occurring within living organisms. Bioelectric potentials are generated by a variety of biological processes and generally range in strength from one to a few hundred millivolts. In the electric eel, however, currents of one ampere at 600 to 1,000 volts are generated. A brief treatment of bioelectricity follows.

Bioelectric effects were known in ancient times from the activity of such electric fishes as the Nile catfish and the electric eel. The experiments of Luigi Galvani and Alessandro Volta in the 18th century on the connection between electricity and muscle contraction in frogs and other animals were of importance in the development of the sciences of physics and physiology. In modern times the measurement of bioelectric potentials has become a routine practice in clinical medicine. Electrical effects originating in active cells of the heart and the brain, for example, are commonly monitored and analyzed for diagnostic purposes.

Bioelectric potentials are identical with the potentials produced by devices such as batteries or generators. In nearly all cases, however, a bioelectric current consists of a flow of ions (*i.e.,* electrically charged atoms or molecules), whereas the electric current used for lighting, communication, or power is a movement of electrons. If two solutions with different concentrations of an ion are separated by a membrane that blocks the flow of the ions between them, the concentration imbalance gives rise to an electric-potential difference between the solutions. In most solutions, ions of a given electric charge are accompanied by ions of opposite charge, so that the solution itself has no net charge. If two solutions of different concentrations are separated by a membrane that allows one kind of ion to pass but not the other, the concentrations of the ion that can pass will tend to equalize by diffusion, producing equal and

opposite net charges in the two solutions. In living cells the two solutions are those found inside and outside the cell. The cell membrane separating inside from outside is semipermeable, allowing certain ions to pass through while blocking others. In particular, nerve- and muscle-cell membranes are slightly permeable to positive potassium ions, which diffuse outward, leaving a net negative charge in the cell.

The bioelectric potential across a cell membrane is typically about 50 millivolts; this potential is known as the resting potential. All cells use their bioelectric potentials to assist or control metabolic processes, but some cells make specialized use of bioelectric potentials and currents for distinctive physiological functions. Examples of such uses are found in nerve and muscle cells. Information is carried by electric pulses (called action potentials) passing along nerve fibres. Similar pulses in muscle cells accompany muscular contraction. In nerve and muscle cells, chemical or electrochemical stimulation results in temporary changes in the permeability of cell membranes, allowing the electric potential between inside and outside to discharge as a current that is propagated along nerve fibres or that activates the contractile mechanism of muscle fibres. The transport of sodium ions is involved in the production of action potentials. Among other cells in which specialized functions are dependent on the maintenance of bioelectric potentials are the receptor cells sensitive to light, sound, and touch and many of the cells that secrete hormones or other substances.

Various fishes, both marine and freshwater, have developed special organs that are capable of generating substantial electric discharges, while others have tissues that can sense feeble electric fields in water. In more than 200 fish species, the bioelectric organ is involved in selfdefense or hunting. The torpedo, or electric ray, and the electric eel have especially powerful electric organs, which they apparently use to immobilize or kill prey. The electric eel has three pairs of electric organs; they constitutemost of the mass of the body and about fourfifths of the total length of the fish. This fish is reputed to be able to generate a sufficiently powerful electric shock to stun a man. Electric rays have two large, disk-shaped electric organs, one on each side of the body, that contribute to the disklike shape of the body. The electric catfish of Africa, the knife fish of Latin America, and the stargazers probably use their bioelectric organs as sense organs in the detection of other fishes.

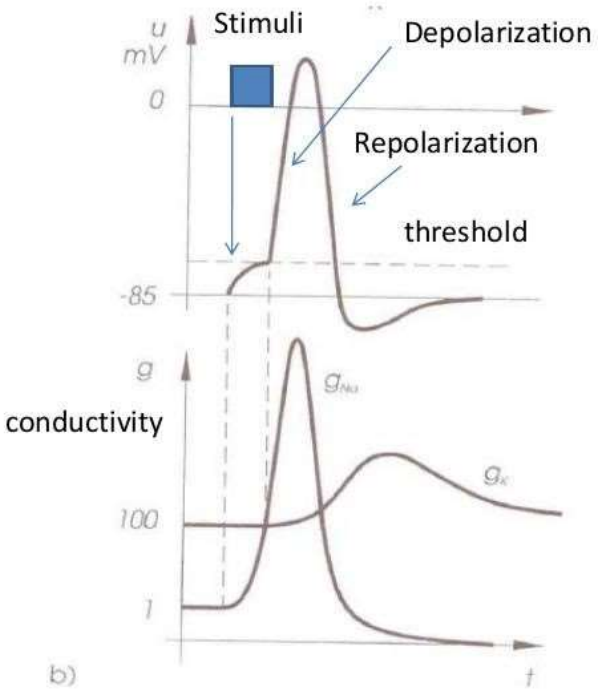
The basic element of a bioelectric organ is a flattened cell called an electroplaque. Large numbers of electroplaques are arranged in series and in parallel to build up voltage and current-producing capacity of the electric organ. Fishes deliver a sudden discharge of electricity by timing the nervous impulses that activate individual electroplaques, thereby providing simultaneous action of the entire array.

Resting potential

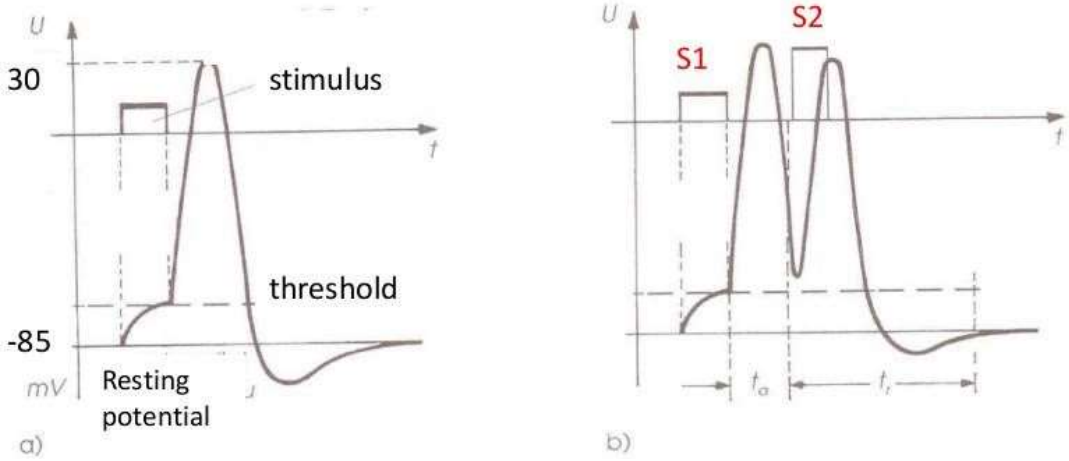
Bioelectric potentials are a result of electrochemical activity of excitable cells (in neuros, muscular or glandular system) The resting potential of a cell – steady difference in electric potentials between internal and external environment of the cell. Typical values of resting potentials are in range of -50 mV to -100 mV (reference point out of the cell). action potential

• Stimulus:
– Mechanical
– Chemical
– Electrical

• Sudden increases of membrane conductance for Na + ions (1000 times more) - change in polarity of the voltage – depolarization.



Action potential, showing depolarisation and repolarisation b) Changes in conductivity for sodium and potassium during the action potential



a) Action potential b) Two consecutive action potentials, caused by stimuli S1 and S2. Note that the magnitude of S2 is larger than magnitude of S1

After commencement of the action potential , the process can not be stopped by any subsequent stimulus - as long as this state lasts we are talking about the absolute refractory period t_o.
When the process starts to calm down and return power to the value at rest, it is possible to re-trigger action potentials using more intense stimulus, even though the voltage has not reached the value at rest - the time when it is possible to re-create the action potentials with a greater intensity of stimulus is called the relative refractory time, t_r

The course:

– The stimulus reaches the threshold
– Increasing membrane permeability for Na + ions
– After that, permeability for K + increases and Na + ions permeability decrease
– Reducing permeability for K + ions
– Active ejection of Na + and injection of K + ions

 Excitable cells have the ability to conduct action potentials when adequatly stimulated.

- An adequate stimulus causes depolarisation of the membrane large enough to reach and exceed the stimulation threshold of the membrane.
- Adequate excitation causes an action potential, which follows the all –or-none rule. The action potential travals along the membrane at constant velocity and without attenuation.
- At rest, the cell is said to be polarized.
- After the cell is excited, the potenetial is decreasing – depolarisation of the cell membrane.
- Returning of the cell potential to the resting value is called repolarisation.
- After repolarisation, for a short period of time, the cell potential is increased which is called hyperpolarisation. During that period, a stimulus has to be of larger magnitude in order to excite a cell.

Propagation of action potentials in nerves

The charge distributions that would be expected to occur along the membrane of that axon is like that Positive charges exist on the outside of the axon and negative charges on the inside. Now consider the consequences of delivering some stimulus to a point in the middle of the axon. If the depolarization is sufficiently large, voltage-dependent sodium channels will be opened, and an action potential will be initiated.

Consider for the moment "freezing" the action potential at its peak value. Its peak value now will be about +40 mV inside with respect to the outside. Unlike charges attract, so the positive charge will move to the adjacent region of the membrane. As the charge moves to the adjacent region of the membrane, the adjacent region of the membrane will depolarize. If it depolarizes sufficiently, as it will, voltage-dependent sodium channels in the adjacent region of the membrane will be opened and a "new" action potential will be initiated. This charge distribution will then spread to the next region and initiate other "new" action potentials. One way of viewing this process is with a thermal analogue. You can think of an axon as a piece of wire coated with gunpowder (the gunpowder is analogous to the sodium channels). If a sufficient stimulus (heat) is delivered to the wire, the gunpowder will ignite, generate heat, and the heat will spread along the wire to adjacent regions and cause the gunpowder in the adjacent regions to ignite.

Propagation Velocity

A great variability is found in the velocity of the propagation of action potentials. In fact, the propagation velocity of the action potentials in nerves can vary from 100 meters per second (580 miles per hour) to less than a tenth of a meter per second (0.22 miles per hour). Why do some axons propagate information very rapidly and others slowly? In order to understand how this process works, it is necessary to consider two so-called passive properties of membranes, the time constant and the space or length constant.

The time constant is a function of two properties of membranes, the membrane resistence (R_m) and the membrane capacitance (C_m). R_m is the inverse of the permeability; the higher the permeability, the lower the resistance, and vice versa. Membranes, like the physical devices known as capacitors, can store charge. When a stimulus is delivered, it takes time to charge up the membrane to its new value.

$T = R_m Cm$

The space constant is a passive property of membranes. Although it influences the rate of propagation of the action potentials, it is an independent process.

$$\lambda = \sqrt{\frac{dR_m}{4R_i}}$$

The length constant can be described in terms of the physical parameters of the axon, where d is the diameter of the axon, R_m is, as before, the membrane resistance, the inverse of the permeability, and R_i is the internal resistance (resistance of the axoplasm). R_i is an indicator of the ability of charges to move along the inner surface of the axon. A small subthreshold change in the charge distribution at one point along an axon will spread along the axon, but as it does some will diffuse back out of the membrane and some will continue to move along the axon. If the resistance of the membrane (R_m) is high, less will leak out and relatively more will move along the axon.

$$Velocity \quad \alpha \quad \frac{1}{C_m}\sqrt{\frac{d}{4R_mR_i}}$$

The smaller the time constant, the more rapid will be the propagation velocity. If the space constant is large, a potential change at one point would spread a greater distance along the axon and bring distance regions to threshold sooner. Therefore, the greater the space constant, the more rapidly distant regions will be brought to threshold and the more rapid will be the propagation velocity. Thus, the propagation velocity is directly proportional to the space constant and inversely proportional to the time constant.

Rhythmic excitation of heart

Here is the explanation of generating rhythmical electrical impulses to cause rhythmical contraction of the heart muscle. The ends of the sinus nodal fibers connect directly with surrounding atrial muscle fibers.

Cardiac impulse does not travel from atria into ventricles too rapidly. This delay allows time for the atria to empty their blood into the ventriclesbefore ventricular contraction begins. A-V node and its adjacent conductive fibers delay this transmission and are located on posterior wall of the right atrium immediately behind the tricuspid valve. Impulse reaches the A-V node about 0.03s.

Delay of another 0.09 second in the A-V node itself before the impulse enters the penetrating portion of the A-V bundle, where it passes into the ventricles. A final delay of another 0.04

second occurs mainly in this penetrating A-V bundle. Total delay in the A-V nodal and A-V bundle system is about 0.13s. This, in addition to the initial conduction delay of 0.03s from the sinus node to the A-V node, makes a total of 0.16s.
After reaching, impulse is transmitted through the ventricular musclemass by the ventricular muscle fibers themselves at 0.3-0.5m/s. The cardiac muscle wraps around the heart in a double spiral, with fibrous septabetween the spiralling layers. Therefore, transmission from the endocardial surface to the epicardial surface of the ventricle requires as much as another 0.03 s. The total time for transmission of the cardiac impulse from the initial bundle branches to the last of the ventricular muscle fibers in the normal heart is about 0.06 second.
Discharge rate (70-80x) is considerably faster than the A-V node (15-40x)or Purkinje fibers (15-40x). SA impulses conducted to both AV and Purkinje fibers.SA node discharges before AV and Purkinje fibers can excite themselves. A impulses discharges both AV and PF, before their self-excitation. SA node controls the beat of the heart. A pacemaker with abnormal sequence contraction is an ―ectopic‖ pacemaker. Stokes-Adams syndrome.
Stimulation releases acetylcholine which increases K-channel permeability causing hyperpolarization. This hormone has two major effects on the heart, decreased SA node rhythm, Decreased excitability of the A-V node (impulse transmission slows down.

Module -2

Specifications of instruments

▪ **Resolution** -- the smallest amount of input signal change that the instrument can detect reliably. This term is determined by the instrument noise (either circuit or quantization noise). For example, if you have a noiseless voltmeter that has 5 1/2 digits displayed and is set to the 20 V input range, the resolution of this voltmeter is 100 μV. This can be determined by looking at the change associated with the least significant digit.

Now, if this same voltmeter had 10 counts of peak-to-peak noise, the effective resolution would be decreased because of the presence of the noise. Because of the Gaussian distribution of the noise, in this case the effective resolution would be 0.52 ´ 1 mV. In general when you have a measurement system that has X counts of Gaussian noise, the effective resolution of the system is given by

$$\text{Resolution} = 0.52 \bullet \text{X counts or volts}$$

A flicker-free measurement system or device has an effective resolution equal to 1 count.

▪ **Effective Number of Digits (ENOD)** -- a performance parameter for an instrument or digitizer, defined in terms of the total range and the resolution:

$$\text{Effective Number of Digits} = \log_{10}\left[\frac{\text{total range}}{\text{resolution at that range}}\right] \quad (1)$$

ENOD = $\log_{10}((20-(-20))/0.52\ \text{mV}) = 4.886$ for the noisy meter given in the example above, and for the noiseless instrument ENOD = $\log_{10}((20-(-20))/100\ \mu\text{V}) = 5.60206$.

Note: Peak-to-peak = rms x 6.6 for agreement with mathematical formulas

▪ **Digits Displayed and Overranging** -- the number of digits displayed by the readout of a DMM. It is often specified as a certain number of full digits (i.e. digits that can display values from 0 to 9) and an additional overrange digit referred to as a 1/2 digit. That 1/2 digit typically shows only the values 0 or 1. For example, a 6 1/2 digit display has a 7-digit readout, but the most significant digit can read 0 or 1 while the other 6 digits can take any value from 0 to 9. Hence, the range of counts is ±1,999,999. This should not be confused with resolution; a DMM can have many more digits displayed than its effective resolution.

Note: The 1/2 digit has been referred to by DMM manufacturers as any digit that is not a full digit. A full digit can take any value from 0 to 9.

▪ **Number of Counts** -- the number of divisions into which a given measurement range is divided. For example, a traditional 5 1/2 digit voltmeter has ±199,999 counts (from +199,999 to -199,999) or 399,999 total counts. The weight of a count is given by the following expression (2):

$$\text{Count Weight} = \frac{\text{Total Range}}{\text{Total Counts}} \qquad (2)$$

Number of Least Significant Bits -- the number of divisions into which a given measurement range is divided. For example, a 12-bit digitizer has 4096 LSBs. (In a bipolar 12-bit system, the range of returned codes is typically -2048 to 2047.) The weight of an LSB is given by the following formula (3):

$$\text{LSB Weight} = \frac{(+\text{veRange}) - (-\text{veRange})}{\text{Number of LSBs}} \qquad (3)$$

and the number of LSBs for an *n*-bit digitizer is given by (4)

$$\text{No. of LSBs} = 2^n \qquad (4)$$

Note: LSBs and counts are the same. A non-DMM digitizer usually refers to its counts as the number of LSBs. This definition is given here for comparison purposes.

▪ **Sensitivity** -- a measure of the smallest signal the instrument can measure. Usually, this is defined at the lowest range setting of the instrument. For example, an AC meter with a lowest measurement range of 10 V may be able to measure signals with 1 mV resolution but the smallest detectable voltage it can measure may be 15 mV. In this case, the AC meter has a resolution of 1 mV but a sensitivity of 15 mV. ▪ **Accuracy** -- a measure of the capability of the instrument to faithfully indicate the value of the measured signal. This term is not related to

resolution; however, it can never be better than the resolution of the instrument. The accuracy is often specified as:

$$\text{Accuracy} = (\%\ \text{of reading}) + \text{offset} \qquad (5)$$

For example, a 5 1/2 digit voltmeter can have an accuracy of 0.0125% of reading + 24 μV on its 2.5 V range which results in an error of 149 μV when measuring a 1V signal. On the other hand, the resolution of this same voltmeter is 12 μV, 12 times better than the accuracy. Keep in mind that the accuracy of your measurement is affected by several factors and we will discuss these factors later in this paper.

- **Precision** -- a measure of the stability of the instrument and its capability of resulting in the same measurement over and over again for the same input signal. It is given by:

$$\text{Precision} = 1 - \left|X_n - Av(X_n)\right| / \left|Av(X_n)\right| \qquad (6)$$

where X_n = the value of the nth measurement and $Av(X_n)$ = the average value of the set of n measurement.

For instance, if you are monitoring a constant voltage of 1 V, and you notice that your measured value changes by 20 μV between measurements, for example, then your measurement precision is

$$\text{Precision} = (1 - 20\mu\text{V}/1\text{V}) \times 100 = 99.998\%$$

which is 6.25 times better than the voltmeter accuracy. This specification is most valuable when you are using the voltmeter to calibrate a device or performing relative measurements.

- **Normal Mode** -- an indication of a differential change at the inputs of the measuring instrument.
- **Common Mode** -- an indication of an equal change on both inputs of the measuring instrument.
- **Normal-Mode Rejection Ratio (NMRR)** -- describes the ability of the instrument to reject a normal (differential) signal, it is given by the following formula:

$$\text{NMRR} = 20\log(V_{measured}/V_{in}) \qquad (7)$$

where V_{in} is applied differentially to the instrument inputs, and $V_{measured}$ is the value indicated by the DMM. This specification is useful for measurement systems that have filters to eliminate signals at a given frequency or over a range of frequencies. For systems that do not have filters, the NMRR is 0 dB. This specification, which is often used to indicate the capability of the instrument to reject 50 or 60 Hz, is valid only at the specified frequency and useful only when making DC measurements.

For example, if you are measuring 1 mVDC with a DMM that specifies a NMRR of 130 dB at 60 Hz, and you have a normal-mode interference (noise) of 100 mVrms, then your resulting measurement error is

$$\text{Measurement Error} = 10\text{^}(-130/20) \times 100\ \text{mV} = 31.6\ \text{nV}$$

which is 0.003 percent of your measured signal instead of the 10,000 percent error that the 100 mV interference implies.

- **Common-Mode Rejection Ratio (CMRR)** -- a measure of the capability of an instrument to reject a signal that is common to both input leads. For instance, if you are measuring a thermocouple in a noisy environment, the noise from the environment appears on both input leads. Therefore, this noise is a common-mode signal that is rejected by the CMRR of the instrument. The CMRR is defined by the following equation:

$$\text{CMMR} = 20\log(\text{Differential Gain}/\text{Common-Mode Gain}) \qquad (8)$$

This specification is very important because it indicates how much of the common-mode signal will affect your measurement. CMRR is also frequency dependent. An equivalent equation to represent CMRR is as follows:

$$20\log(V_{inmeasured}/V_C) \qquad (9)$$

where $V_{inmeasured}$ is the indicated value for an applied common-mode voltage VC

- **Effective Common-Mode Rejection Ratio (ECMRR)** -- only valid for DC measurements, it is the sum of CMRR and NMRR at a given frequency. It is the effective rejection on a given noise signal that is applied to both input leads because it is rejected first by the CMRR capability of the instrument and then again by its NMRR capability. This specification is mostly useful at the power line frequencies, where most of the noise resides.

- **Nonlinearity** -- the amount of distortion that is applied on the signal. This distortion, varies with signal input level and or signal frequency. If we went back and looked at the accuracy specifications, we would notice that this specification is based on the assumption that the instrument has a transfer function described as follows:

$$V_{displayed} = mV_{in} + b \qquad (10)$$

In this accuracy specification, the percent and offset terms apply to the degree of accuracy to which we know the slope *m* and intercept *b* of the transfer function. However, many measurement systems have transfer functions that are more accurately modeled as 2nd and 3rd order polynomials. To keep the calibration simple the transfer function is assumed to be linear and a nonlinearity error is specified to compensate for the 2nd or 3rd order part of the transfer function. This error is given as a function of percent of range and not of reading. The reason for this is that the peak nonlinearity error could occur at any point over the full-scale input

range. For example, given a nonlinearity of 0.0015% and a range of 2 V, the voltmeter has an additional error of 0.0015%×2 = 30 μV. This error is sometimes lumped in the offset error indicated in the accuracy table; be careful not to count it twice in your error budget.

- **Crest Factor** -- the ratio of the peak voltage to rms voltage of a signal, which is given by the following formula:

$$\text{Crest Factor} = (V_{peak}/V_{rms}) \qquad (11)$$

For a sine wave the crest factor is 1.414, for a square wave the crest factor is 1. This specification is important because it indicates the maximum peak value of an arbitrary waveform that the DMM can handle without overloading. The crest factor also affects the accuracy of the AC measurement. For example, given a certain DMM with an AC accuracy of 0.03% (this is always specified for sine waves), and has an additional error of 0.2% for crest factors between 1.414 and 5, then the total accuracy for measuring a triangular wave (crest factor = 1.73) is 0.03% + 0.2% = 0.23%.

- **Root Mean Square (rms)** -- a value assigned to an AC signal that represents the amount of DC signal required to produce an equivalent amount of heat in the same load. Its mathematical equation is given by:

$$V_{rms} = \sqrt{\left[\frac{1}{T} \bullet \int V(t)^2 dt\right]} \qquad (12)$$

or simplified to:

$$V_{rms} = \sqrt{\{Average[V(t)^2]\}} \qquad (13)$$

- **True rms** -- a specific method of measuring the rms value of a signal. This method results in the most accurate rms value regardless of the shape of the waveform. Other methods of measuring rms values exist, such as the rectifier or mean absolute deviation method; however, these methods are accurate only for sine wave signals.

- **2-Wire Resistance Measurement** -- a method of measuring resistance that uses only two test leads. To measure resistance, the voltmeter typically passes a current through the resistor of interest and then measures the voltage developed across this resistor. In this method, both the injected current and the sensed voltage use the same pair of test leads.

- **4-Wire Resistance Measurement** -- a method of measuring resistance that uses four test leads. One pair is used for the injected current, the other pair is used for sensing the voltage across the resistor. This more accurate method is recommended for measuring resistance below

100 ohms. The improved accuracy is achieved because the test leads resistances are removed from the measurement path.

Static and Dynamic characteristics

The performance characteristics of an instrument are mainly divided into two categories: i) Static characteristics ii) Dynamic characteristics.

Static characteristics:

The set of criteria defined for the instruments, which are used to measure the quantities which are slowly varying with time or mostly constant, i.e., do not vary with time, is called _static characteristics‘.

The various static characteristics are:

i) Accuracy ii) Precision iii) Sensitivity iv) Linearity v) Reproducibility vi) Repeatability vii) Resolution viii) Threshold ix) Drift x) Stability xi) Tolerance xii) Range or span.

Accuracy:

It is the degree of closeness with which the reading approaches the true value of the quantity to be measured. The accuracy can be expressed in following ways:

a) Point accuracy: Such accuracy is specified at only one particular point of scale. It does not give any information about the accuracy at any other Point on the scale.

b) Accuracy as percentage of scale span: When an instrument as uniform scale, its 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. Precision: It is the measure of reproducibility i.e., given a fixed value of a quantity, precision is a measure of the degree of agreement within a group of measurements. The precision is composed of two characteristics:

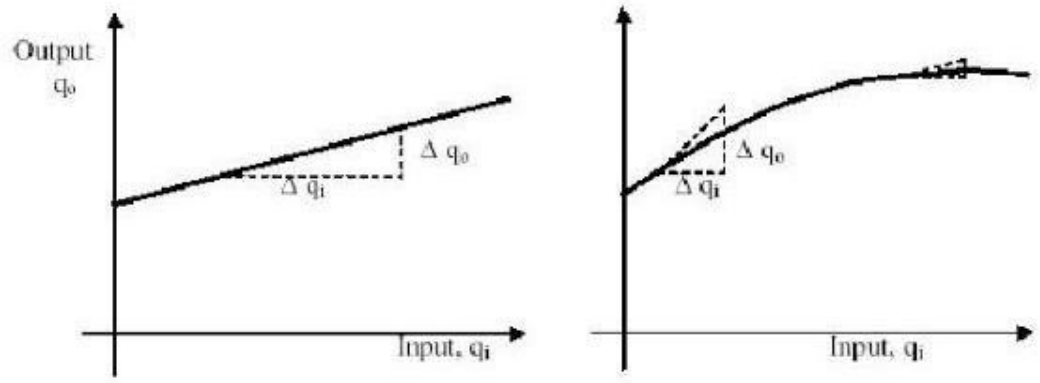
i) Conformity: Consider a resistor having true value as 2385692 , which is being measured by an ohmmeter. But the reader can read consistently, a value as 2.4 M due to the nonavailability of proper scale. The error created due to the limitation of the scale reading is a precision error.

ii) Number of significant figures: The precision of the measurement is obtained from the number of significant figures, in which the reading is expressed. The significant figures convey the actual information about the magnitude & the measurement precision of the quantity. The precision can be mathematically expressed as:

$$P = 1 - \left| \frac{Xn - \overline{Xn}}{\overline{Xn}} \right|$$

Where, P = precision Xn = Value of nth measurement Xn = Average value the set of measurement values.

Sensitivity: The sensitivity denotes the smallest change in the measured variable to which the instrument responds. It is defined as the ratio of the changes in the output of an instrument to a change in the value of the quantity to be measured. Mathematically it is expressed as,



$$\text{Sensitivity} = \frac{\text{Infinitesimal change in output}}{\text{Infinitesimal change in input}}$$

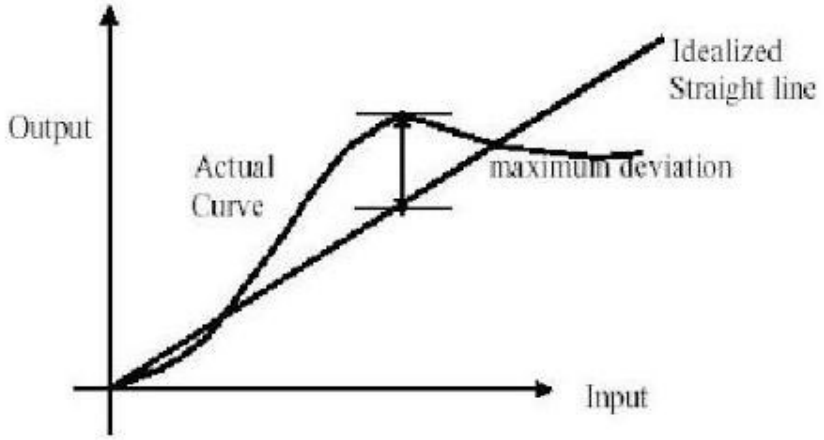
$$= \frac{\Delta qo}{\Delta qi}$$

Thus, if the calibration curve is liner, as shown, the sensitivity of the instrument is the slope of the calibration curve. If the calibration curve is not linear as shown, then the sensitivity varies with the input. Inverse sensitivity or deflection factor is defined as the reciprocal of sensitivity. Inverse sensitivity or deflection factor = 1/ sensitivity

$$= \frac{\Delta qi}{\Delta qo}$$

Linearity:

The linearity is defined as the ability to reproduce the input characteristics symmetrically & linearly. The curve shows the actual calibration curve & idealized straight line.

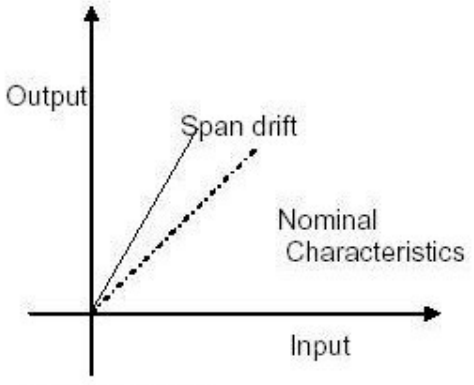


$$\% \text{ non-linearity} = \frac{\text{Max. deviation of output from idealized straight line}}{\text{Full scale reading}}$$

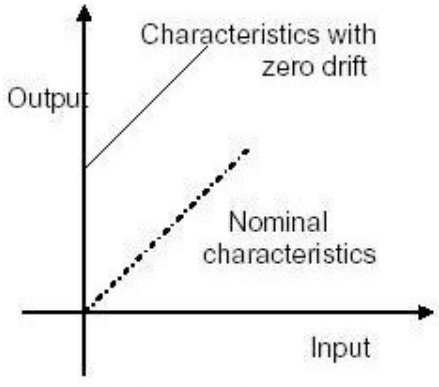
Reproducibility: It is the degree of closeness with which a given value may be repeatedly measured. It is specified in terms of scale readings over a given period of time.

Repeatability: It is defined as the variation of scale reading & random in nature Drift: Drift may be classified into three categories:

a) zero drift: If the whole calibration gradually shifts due to slippage, permanent set, or due to undue warming up of electronic tube circuits, zero drift sets in.



(Fig) span drift



(fig) zero drif

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

c) Zonal drift: In case the drift occurs only a portion of span of an instrument, it is called zonal drift.

Resolution:
If the input is slowly increased from some arbitrary input value, it will again be found that output does not change at all until a certain increment is exceeded. This increment is called resolution.
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.
Stability: It is the ability of an instrument to retain its performance throughout is specified operating life.
Tolerance: The maximum allowable error in the measurement is specified in terms of some value which is called tolerance.
Range or span: The minimum & maximum values of a quantity for which an instrument is designed to measure is called its range or span.

Dynamic characteristics:

The set of criteria defined for the instruments, which are changes rapidly with time, is called _dynamic characteristics‘.
The various static characteristics are:
i) Speed of response ii) Measuring lag iii) Fidelity iv) Dynamic error

Speed of response: It is defined as the rapidity with which a measurement system responds to changes in the measured quantity.
Measuring lag: It is the retardation or delay in the response of a measurement system to changes in the measured quantity. The measuring lags are of two types:
a) Retardation type: In this case the response of the measurement system begins immediately after the change in measured quantity has occurred.
b) Time delay lag: In this case the response of the measurement system begins after a dead time after the application of the input.

Fidelity: It is defined as the degree to which a measurement system indicates changes in the measurand quantity without dynamic error.

Dynamic error: It is the difference between the true value of the quantity changing with time & the value indicated by the measurement system if no static error is assumed. It is also called measurement error.

Classification of errors

Errors will creep into all measurement regardless of the care which is exerted. But it is important for the person performing the experiment to take proper care so that the error can be minimized. Some of the errors are of random in nature, some will be due to gross blunder on the part of the experimenter and other will be due to the unknown reasons which are constant in nature. Thus, we see that there are different sources of errors and generally errors are classified mainly into three categories as follows:

(a) Gross errors (b) Systematic errors (c) Random errors

Gross Errors

These errors are due to the gross blunder on the part of the experimenters or observers. These errors are caused by mistake in using instruments, recording data and calculating measurement results. For example: A person may read a pressure gage indicating 1.01 N/m2 as 1.10 N/m2 . Someone may have a bad habit of memorizing data at a time of reading and writing a number of data together at later time. This may cause error in the data. Errors may be made in calculating the final results. Another gross error arises when an experimenter makes use (by mistake) of an ordinary flow meter having poor sensitivity to measure low pressure in a system.

Systematic Errors

These are inherent errors of apparatus or method. These errors always give a constant deviation. On the basis of the sources of errors, systematic errors may be divided into following sub-categories :

i)Constructional Error

None of the apparatus can be constructed to satisfy all specifications completely. This is the reason of giving guarantee within a limit. Therefore, a manufacturers always mention the minimum possible errors in the construction of the instruments. Errors in Reading or Observation Following are some of the reasons of errors in results of the indicating instruments :

(a) Construction of the Scale : There is a possibility of error due to the division of the scale not being uniform and clear.

(b) Fitness and Straightness of the Pointer : If the pointer is not fine and straight, then it always gives the error in the reading.

(c) Parallax : Without a mirror under the pointer there may be parallax error in reading.

(d) Efficiency or Skillness of the Observer : Error in the reading is largely dependent upon the skillness of the observer by which reading is noted accurately.

ii)Determination Error

It is due to the indefiniteness in final adjustment of measuring apparatus. For example, Maxwell Bridge method of measuring inductances, it is difficult to find the differences in sound of head phones for small change in resistance at the time of final adjustment. The error varies from person to person. **iii)Error due to Other Factors**

Errors in Measurement Temperature Variation
Variation in temperature not only changes the values of the parameters but also brings changes in the reading of the instrument. For a consistent error, the temperature must be constant.

Effect of the Time on Instruments

There is a possibility of change in calibration error in the instrument with time. This may be called ageing of the instrument.

Effect of External Electrostatic and Magnetic Fields

These electrostatic and magnetic fields influence the readings of instruments. These effects can be minimized by proper shielding.

Mechanical Error

Friction between stationary and rotating parts and residual torsion in suspension wire cause errors in instruments. So, checking should be applied. Generally, these errors may be checked from time to time.

Random Errors

After corrections have been applied for all the parameters whose influences are known, there is left a residue of deviation. These are random error and their magnitudes are not constant. Persons performing the experiment have no control over the origin of these errors. These errors are due to so many reasons such as noise and fatigue in the working persons. These errors may be either positive or negative. To these errors the law of probability may be applied. Generally, these errors may be minimized by taking average of a large number of readings.

Analysis Of The Errors

When an experiment is performed and some data are obtained, then it is required to analyse these data to determine the error, precision and general validity of the experimental measurements. Bad data due to obvious blunder or reason may be discarded immediately. We cannot throw out the data because they do not conform with our hopes and expectations unless we see something obviously wrong. If such bad points fall outside the range of normally expected random deviations, they may be discarded on the basis of some consistent statistical analysis. The elimination of data point must be consistent and should not be dependent on human whims and biased based on what _ought to be‘. In many instances, it is very difficult for the individual to be consistent and unbiased. The presence of a deadline, disgust with previous experimental failures, and normal impatience all can influence rational thanking processes. However, the competent experimentalist will strive to maintain consistency in the primary data analysis.

Statistical Analysis of Experimental Data

It is important to define some pertinent terms before discussing some important methods of statistical analysis of experimental data. **Arithmetic Mean**
When a set of readings of an instrument is taken, the individual readings will vary somewhat from each other, and the experimenter is usually concerned with the mean of all the readings. If each reading is denoted by *xi* and there are *n* readings, the arithmetic mean is given by

$$x_m = \frac{1}{n}\sum_{i=1}^{n} x_i$$

Deviation

The deviation, *d*, for each reading is given by

$$d_i = x_i - x_m$$

We may note that the average of the deviations of all readings is zero since

$$d_i = \frac{1}{n}\sum_{i=1}^{n} d_i = \frac{1}{n}\sum_{i=1}^{n} (x_i - x_m)$$

$$= x_m - \frac{1}{n}(nx_m)$$

$$= 0$$

The average of the absolute value of the deviations is given by

$$|\bar{d}_i| = \frac{1}{n}\sum_{i=1}^{n} |d_i|$$

$$= \frac{1}{n}\sum_{i=1}^{n} [x_i - x_m]$$

Note that the quantity is not necessarily zero.

Standard Deviation

It is also called root mean-square deviation. It is defined as

$$\sigma = \left[\frac{1}{n}\sum_{i=1}^{n} (x_i - x_m)^2\right]^{1/2}$$

Variance

The square of standard deviation is called variance. This is sometimes called the population or biased standard deviation because it strictly applies only when a large number of samples is taken to describe the population.

Geometrical mean

It is appropriate to use a geometrical mean when studying phenomena which grow in proportion to their size. This would apply to certain biological processes and growth rate in financial resources. The geometrical mean is defined by

$$x_g = [x_1 \,.\, x_2 \,.\, x_3 \ldots x_n]^{\frac{1}{n}}$$

Example

The following readings are taken of a certain physical length. Compute the mean reading, standard deviation, variance and average of the absolute value of the deviation using the biased bases.

Reading	1	2	3	4	5	6	7	8	9	10
x_i **(cm)**	5.30	5.73	6.77	5.26	4.33	5.45	6.09	5.64	5.81	5.75

Solution:

$$x_m = \frac{1}{n}\sum_{i=1}^{n} x_i = \frac{1}{10}(56.13)$$

$$= 5.613 \text{ cm}$$

The other quantities are computed with the aid of the following table

Reading	$d_i = x_i - x_m$	$(x_i - x_m)^2$
1	– 0.313	0.09797
2	0.117	0.01369
3	1.157	1.33865
4	– 0.353	0.12461
5	– 1.283	16.4609
6	– 0.163	0.02657
7	0.477	0.22753
8	0.027	0.00729
9	0.197	0.03881
10	1.137	0.01877

$$\sigma = \left[\frac{1}{n}\sum_{i=1}^{n}(x_i - x_m)^2\right]^{1/2}$$

$$= \left[\frac{1}{10}(3.533)\right]^{1/2} = 0.5944 \text{ cm}$$

$$\sigma^2 = 0.3533 \text{ cm}^2$$

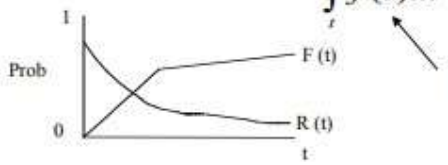
$$|\bar{d}_i| = \frac{1}{n}\sum_{i=1}^{n}|d_i| = \frac{1}{n}\Sigma|x_i - x_m|$$

$$= \frac{1}{10} \times 4.224 = 0.4224 \text{ cm}$$

Reliability

Definition – Reliability is the probability that a system will perform in a satisfactory manner for a given period of time when used under specified operating conditions.
The Reliability Function is:

– $R(t)=P(T>t)=1-F(t)=\int_t^{\infty} f(t)dt$



Reliability Density Function

Four ways to determine R(t) for a particular system
– Test many systems to failure. Develop curve empirically.
– Test many subsystems, use historical field data on others, develop subsystem reliability functions, use a reliability system model to combine.
– Extrapolate past experience with similar systems.
– Physical properties--Hypothesize a certain distribution

Accuracy

It is the degree of closeness with which the reading approaches the true value of the quantity to be measured. The accuracy can be expressed in following ways:

a) Point accuracy: Such accuracy is specified at only one particular point of scale. It does not give any information about the accuracy at any other Point on the scale.

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$$P=1-\left|\frac{Xn-\overline{Xn}}{\overline{Xn}}\right|$$

Where, P = precision Xn = Value of nth measurement Xn = Average value the set of measurement values.

Fidelity

It is defined as the degree to which a measurement system indicates changes in the measurand quantity without dynamic error.

Speed of response

It is defined as the rapidity with which a measurement system responds to changes in the measured quantity.

Linearization Technique

There are analog and digital linearization techniques.

Analog Techniques

Initially the analog techniques for linearizing sensor characteristics were developed as analog

signals were used in instrumentation. Later digital instrumentation techniques

Data Acquisition Systems

Data Acquisition = gathering of information in system or process.

- Parameter information (i.e temperature, pressure or flow) gathered by sensors, then convert the information into electrical signals.

- The sensors signals transferred to instrument using medium (i.e wire, optical fiber or wireless link)

Data Acquisition System (DAS) Elements

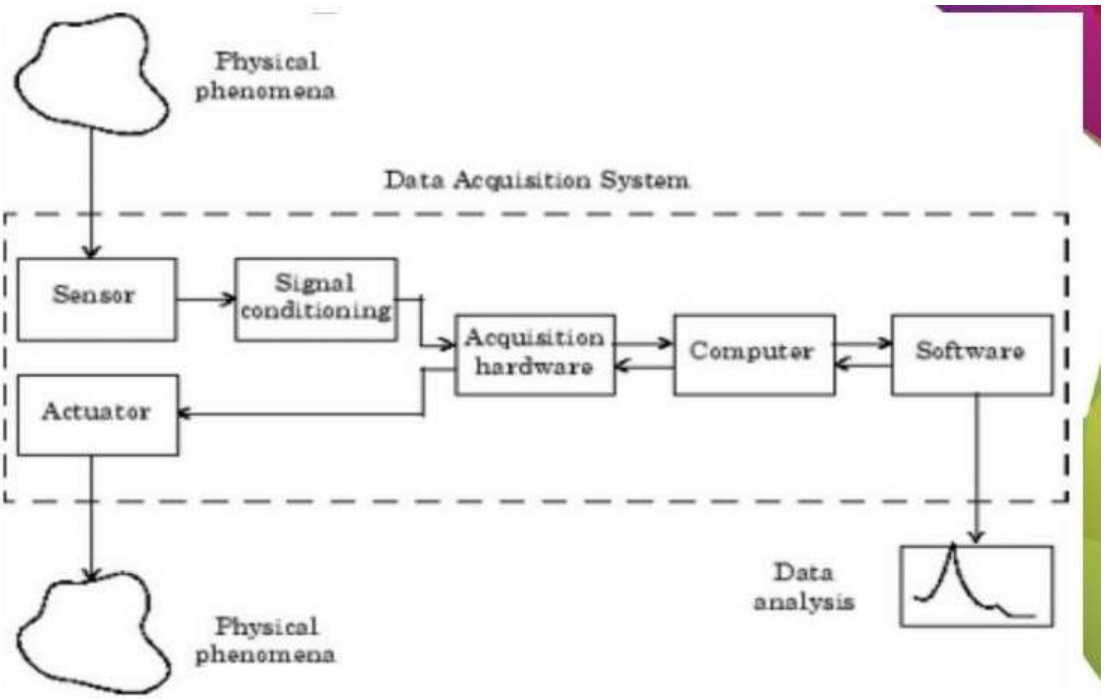
- Signals

- Transducers: Sense physical variables

- Signal-conditioning hardware: to make it readable by an A/D board

- DAQ device or module :Convert the signal into a digital format acceptable by a computer

- Application software :Process, analyze, store, and display the acquired data



Types of DAS

Wireless Data Acquisition Systems

Serial Communication Data Acquisition Systems

USB Data Acquisition Systems

Data Acquisition Plug-in Boards

Detection of physiological parameters using impedance techniques Bipolar Measurement Method

The mathematical principle of electrical impedance measurement is Ohm‘s law,Z=V/I . Thus the most fundamental measuring method is using two electrodes to induce the current (I) and to measure the voltage (V). However, in this bipolar measurement method, because of the existence of electrode polarization, the measured impedance consists of two parts, that is, impedance of measured object and parasitic capacitive impedance on the interface of the electrode-sample ohmic contacts . The parasitic impedance decreases with frequency increasing; thus it can be ignored when frequency is high in bipolar measurement system . Material and configuration of electrodes have an impact on electric field loaded on the tested biological tissue and are important factors in measurements.

Tetrapolar Measurement

To eliminate the electrode polarization for more accurate measurement of impedance, a tetrapolar measurement method was proposed. The parasitic voltage is caused when a current flows through the interface of electrode sample. In tetrapolar system, current inducing and voltage measurement are via two separate electrodes pairs ; thus current is not introduced in the voltage measurement circuit and the parasitic impedance is eliminated. However, in practical terms, electrodes with uniform specific polarization impedance (per unit surface area) over the entire electrode surface are difficult to obtain, which causes the electrode on a potential level different from the one it ought to register.

Skin Impedance

The average electrical properties of stratum corneum and the viable skin underneath were first estimated by Yamamoto & Yamamoto in 1976 by adjusting a tissue circuit equivalent to reflect the measured electrical impedance after applying an 18% sodium chloride solution for 30 minutes before and after stratum corneum stripping, thereby enabling the measurement of the stratum corneum and viable skin respectively. the electrical impedance of intact skin is dominated by the stratum corneum at low frequencies($\lesssim$1 kHz) and by the underlying layers at higher frequencies ($\gtrsim$1 MHz).

Galvanic Skin Response Measurement

The galvanic skin response (GSR, which falls under the umbrella term of electrodermal activity, or EDA) refers to changes in sweat gland activity that are reflective of the intensity of our emotional state, otherwise known as emotional arousal.

Our level of emotional arousal changes in response to the environment we‘re in – if something is scary, threatening, joyful, or otherwise emotionally relevant, then the subsequent change in emotional response that we experience also increases eccrine sweat gland activity. Research has shown how this is linked to emotional arousal.

It is noteworthy that both positive (―happy‖ or ―joyful‖) and negative (―threatening‖ or ―saddening‖) stimuli can result in an increase in arousal – and in an increase in skin conductance. The GSR signal is therefore not representative of the type of emotion, but the intensity of it.

As GSR measurements work by detecting the changes in electrical (ionic) activity resulting from changes in sweat gland activity, the electrodes must be sensitive to these changes, and able to transmit that information to the recording device.Most modern GSR electrodes have an Ag/AgCl (silver-chloride) contact point with the skin. Ag/AgCl electrodes are used as they are cheap, robust, safe for human contact, and of course are able to accurately transmit the signal from the ionic activity.Some electrodes also come prepackaged with ionic gel that can increase the signal fidelity, or ionic gel can be applied to achieve the same effect. Either way, the signal is sent through the electrode, to the wire (usually lead) that passes the information to the GSR device.From here the data is either stored within the device to be later uploaded, is transmitted wirelessly to a computer system, or the signal is sent through a further wired connection to a computer. Different GSR sensors allow different means of transmission, and the choice of each

will depend on the kind of research you‘re carrying out.Skin conductance is captured using skin electrodes which are easy to apply. Data is acquired with sampling rates between 1 – 10 Hz and is measured in units of micro-Siemens (μS).

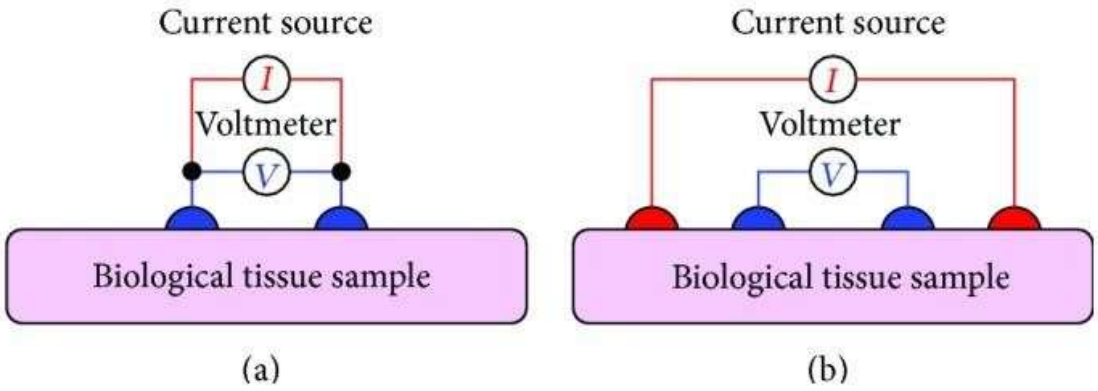
Total Body Impedance

Electrical impedance of a particular part of an object (volume conductor) is estimated by measuring the voltage signal developed across that body part by injecting a constant current signal to the object. Mathematically, the impedance (Z) is measured by dividing the voltage signal measured (V) by the current signal applied (I). Z is complex quantity and it will have a particular phase angle (θ) depending on the tissue properties. In electrical impedance measurement process, the bioelectrical impedance of a body tissue is measured by injecting a low amplitude low frequency alternating current (generally sinusoidal) to the tissue through an array of surface electrodes attached to the tissue surface (tissue boundary). The alternating current is applied to avoid the tissue damage, and hence the bioimpedance measurement is never conducted with the direct current signal.

The bioimpedance $Z\angle\vartheta$ is calculated by dividing the voltage data ($V\angle\vartheta_1$) measured by applied current ($I\angle\vartheta_2$) as shown in

$$Z\angle(\theta)=V\angle(\theta_1)I\angle(\theta_2).$$

The bioimpedance measurement process is conducted by either the two electrode or fourelectrode methods.



(a) impedance measurement using two-electrode technique, (b) impedance measurement using four-electrode technique

As the name tells, the two-electrode method uses only two electrodes for impedance measurement, and hence the current signal injection and voltage measurement are conducted with same electrodes. The two-electrode-method, therefore, suffers from the contact impedance problem and the measurement data contains the voltage drop due to the contact impedance. In the four-electrode method , two separate electrode pairs are used for current injection and voltage measurements, and hence the four-electrode method is found as an impedance measurement method with a linear array of four electrodes attached to the SUT as shown in . The four-electrode method injects a constant amplitude current signal to the SUT through the outer electrodes called current electrodes or the driving electrodes (red colored electrodes in

and the frequency dependent developed voltage signals are measured across two points within the current electrode through the inner electrodes called voltage electrodes or the sensing electrodes (blue colored electrodes).

Cardiac Output

It is also denoted by the symbols is a term used in cardiac physiology that describes the volume of blood being pumped by the heart, in particular by the left or right ventricle, per unit time. Cardiac output is the product of the heart rate (HR), or the number of heart beats per minute (bpm), and the stroke volume (SV), which is the volume of blood pumped from the ventricle per beat; thus, CO = HR × SV. Values for cardiac output are usually denoted as L/min. For a healthy person weighing 70 kg, the cardiac output at rest averages about 5 L/min; assuming a heart rate of 70 beats/min, the stroke volume would be approximately 70 mL.

Because cardiac output is related to the quantity of blood delivered to various parts of the body, it is an important indicator of how efficiently the heart can meet the body's demands for perfusion. For instance, physical exercise requires a higher than resting-level of oxygen to support increased muscle activity, where, in the case of heart failure, actual CO may be insufficient to support even simple activities of daily living; nor can it increase sufficiently to meet the higher metabolic demands stemming from even moderate exercise.

Cardiac output is a global blood flow parameter of interest in hæmodynamics, the study of the flow of blood. The factors affecting stroke volume and heart rate also affect cardiac output.

Neural Activity

Neurons as the main building blocks of central (brain and spinal cord) and peripheral nervous system are well known. Processing and communication of data in various parts of nervous system are performed basically through the propagating variation of transmembrane electric potential of neurons, called action potentials. The electrophysiological function of neurons is the core of memory, cognition, movement, and autonomic functions. Detection, monitoring and recording the electrophysiological activity of neuron(s) are the most important subjects of neurophysiology. The basic therapeutic studies on the various types of neurological disorders including Alzheimer, Parkinson, Multiple Sclerosis (MS), and traumatic brain injuries requires the real time monitoring of the neural activity. The fundamental studies on the different treatments for the neuron based disorders such as pharmacological treatments, excitation with electric/magnetic fields and stem cell therapy are dependent to the devices in which the electrical activity of the neurons are monitored in real time.

Respiratory Activity

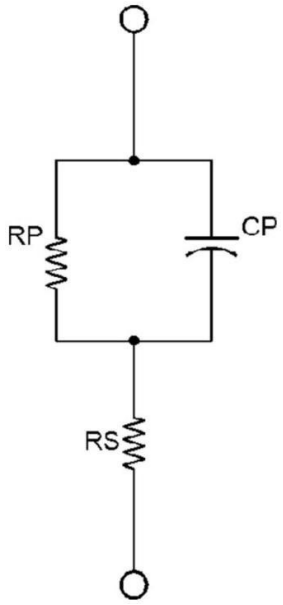
When the respiratory system is mentioned, people generally think of breathing, but breathing is only one of the activities of the respiratory system. The body cells need a continuous supply of oxygen for the metabolic processes that are necessary to maintain life. The respiratory system works with the circulatory system to provide this oxygen and to remove the waste products of metabolism. It also helps to regulate pH of the blood. Respiration is the sequence of events that results in the exchange of oxygen and carbon dioxide between the atmosphere and the body cells. Every 3 to 5 seconds, nerve impulses stimulate the breathing process, or ventilation, which moves air through a series of passages into and out of the lungs. After this, there is an exchange of gases between the lungs and the blood. This is called external

respiration. The blood transports the gases to and from the tissue cells. The exchange of gases between the blood and tissue cells is internal respiration. Finally, the cells utilize the oxygen for their specific activities: this is called cellular metabolism, or cellular respiration. Together, these activities constitute respiration.

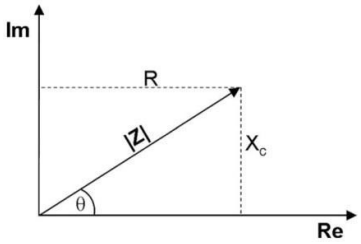
Impedance plethysmography - resistance and capacitance type

Impedance plethysmography is a method of determining changing tissue volumes in the body, based on the measurement of electric impedance at the body surface.

Electrical impedance (Z) is a measure of the opposition to electrical flow through a substance. This value can be broken down into 2 elements, resistance (R) and reactance (Xc). Resistance has passive characteristics, in that its value does not change with frequency. Alternatively, the value of reactance does change with frequency and is found in sources of capacitance. The conventional electrical model for tissue includes resistors and capacitors. Therefore, both resistive and reactive components are present in tissue.



The value of impedance is conventionally represented as a complex number, with the real component being resistance and the complex component being reactance ($Z = r + X_c i$). Alternatively, polar coordinates can be used with resistance and reactance being $Z\cos(\theta)$ and $Z\sin(\theta)$, respectively, where Z is the magnitude of the impedance and θ is the phase angle.



Module 3

Why is Bio Amplifier Required?

Generally, biological/bioelectric signals have low amplitude and low frequency. Therefore, to increase the amplitude level of biosignals amplifiers are designed. The outputs from these amplifiers are used for further analysis and they appear as ECG, EMG, or any bioelectric waveforms. Such amplifiers are defined as Bio Amplifiers or Biomedical Amplifiers.

Basic Requirements for Biological Amplifiers

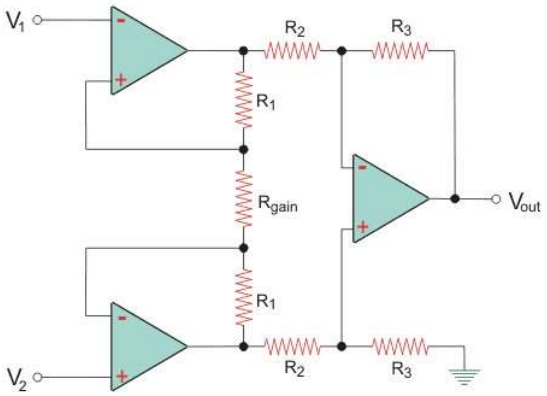
1. The **biological amplifier** should have a high input impedance value. The range of value lies between 2 MΩ and 10 MΩ depending on the applications. Higher impedance value reduces distortion of the signal.
2. When electrodes pick up bio potentials from the human body, the input circuit should be protected. Every bio-amplifier should consist of isolation and protection circuits, to prevent the patients from electrical shocks.
3. Since the output of a bioelectric signal is in millivolts or microvolt range, the voltage gain value of the amplifier should be higher than 100dB.
4. Throughout the entire bandwidth range, a constant gain should be maintained.
5. A bio-amplifier should have a small output impedance.
6. A good bio-amplifier should be free from drift and noise.
7. Common Mode Rejection Ratio (CMRR) value of amplifier should be greater than 80dB to reduce the interference from common mode signal.
8. The gain of the bio-amplifier should be calibrated for each measurement.

Types of Bio Amplifiers

1. Differential Amplifier
2. Operational Amplifier
3. Instrumentation Amplifier
4. Chopper Amplifier
5. Isolation Amplifier

Instrumentation Amplifier

In biomedical applications, high gain and the high input impedance are attained with an instrumentation amplifier. Usually, a 3-amplifier setup forms the instrumentation amplifier circuit. The output from the transducer is given as input to the instrumentation amplifier. Before the signal goes to the next stage, a special amplifier is required with high CMRR, high input impedance and to avoid loading effects. Such a special amplifier is an instrumentation amplifier, which does all the required process.



To each input of the differential amplifier, the non-inverting amplifier is connected. From the figure, the amplifier on the left side acts as non-inverting amplifiers. They are combined together to form the input stage of the instrumentation amplifier. The third op-amp is the difference amplifier, and it is the output of the instrumentation amplifier. The output from the difference amplifier Vout is the difference between two input signals given at the input points. VO1 is the output from op-amp 1 and VO2 is the output from op-amp 2.

$$V_{out} = \frac{R_3}{R_2}(V_{O1} - V_{O2})$$

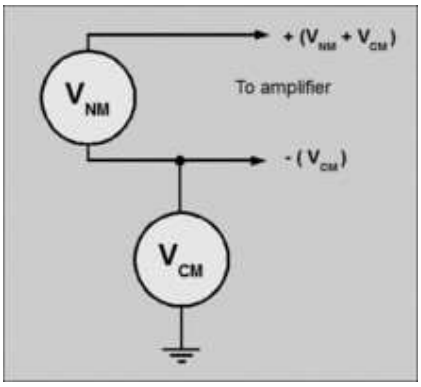
Isolation Amplifier

Isolation amplifiers are a form of differential amplifier that allow measurement of small signals in the presence of a high common mode voltage by providing electrical isolation and an electrical safety barrier. They protect data acquisition components from common mode voltages, which are potential differences between instrument ground and signal ground. Instruments that are applied in the presence of a common mode voltage without an isolation barrier allow ground currents to circulate, leading in the best case to a noisy representation of the signal under investigation. In the worst case, assuming that the magnitude of common mode voltage or current is sufficient, instrument destruction is likely. Isolation amplifiers are used in medical instruments to ensure isolation of a patient from power supply leakage current.

Amplifiers with an isolation barrier allow the front-end of the amplifier to float with respect to common mode voltage to the limit of the barrier's breakdown voltage, which is often 1,000 volts or more. This action protects the amplifier and the instrument connected to it, while still allowing a reasonably accurate measurement.

These amplifiers are also used for amplifying low-level signals in multi-channel applications. They can also eliminate measurement errors caused by ground loops. Amplifiers with internal transformers eliminate external isolated power supply. They are usually used as analogue interfaces between systems with separated grounds.

Isolation amplifiers may include isolated power supplies for both the input and output stages, or may use external power supplies on each isolated portion.



All signal sources are a composite of normal and common mode voltages

All signal sources are a composite of two major components. The normal mode component (V_{NM}) represents the signal of interest and is the voltage that is applied directly across the inputs of the amplifier. The common mode component (V_{CM}) represents the difference in potential between the low side of the normal mode component and the ground of the amplifier that is used to measure the signal of interest (the normal mode voltage).

In many measurement situations the common mode component is irrelevantly low, but rarely zero. Common mode components of only a few millivolts are frequently encountered and largely and successfully ignored, especially when the normal mode component is orders of magnitude larger.

The first indicator that common mode voltage magnitude is competing with the normal mode component is a noisy reproduction of the latter at the amplifier‘s output. Such a situation does not usually define the need for an isolation amplifier, but rather a differential amplifier. Since the common mode component appears simultaneously and in phase on both amplifier inputs, the differential amplifier, within the limits of the amplifier‘s design, can reject it.

However, if the sum of the normal mode and common mode voltages exceeds either the differential amplifier‘s common mode range, or maximum range without damage then the need for an isolation amplifier is firmly established.

Working Principle

Isolation amplifiers are commercially available as hybrid integrated circuits made by several manufacturers. There are three methods of providing isolation.

A transformer-isolated amplifier relies on transformer coupling of a high-frequency carrier signal between input and output. Some models also include a transformer-isolated power supply, that may also be used to power external signal processing devices on the isolated side of the system. The bandwidth available depends on the model and may range from 2 to 20 kHz. The isolation amplifier contains a voltage-to-frequency converter connected through a transformer to a frequency-to-voltage converter. The isolation between input and output is provided by the insulation on the transformer windings.

An optically-isolated amplifier modulates current through an LED optocoupler. The linearity is improved by using a second optocoupler within a feedback loop. Some devices provide up to 60 kHz bandwidth. Galvanic isolation is provided by the conversion of electric current to photonic flux through the space between the LED and the detector, regardless of the intervening medium.

A third strategy is to use small capacitors to couple a modulated high-frequency carrier; the capacitors can stand off large DC or power frequency AC voltages but provide coupling for the much higher frequency carrier signal. Some models on this principle can stand off 3.5 kilovolts and provide up to 70 kHz bandwidth.

Isolation amplifier usage

Isolation amplifiers are used to allow measurement of small signals in the presence of a high common mode voltage. The capacity of an isolation amplifier is a function of two key isolation amplifier specifications:

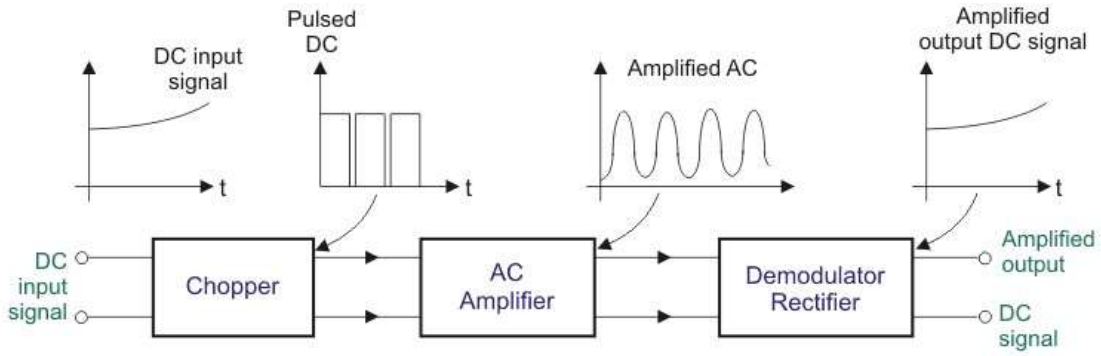
- The amplifier‘s isolation breakdown voltage, which defines the absolute maximum common mode voltage that it will tolerate without damage. Specifications of 1,000 volts and more are common.
- The amplifier‘s common mode rejection ratio (CMRR). The CMRR specification defines the degree to which the common mode voltage will disrupt the normal mode component measurement, and therefore affect measurement accuracy.

The frequency of the common mode voltage can adversely affect performance. Higher frequency common mode voltages create difficulty for many isolation amplifiers due to the parasitic capacitance of the isolation barrier. This capacitance appears as a low impedance to higher frequency signals, and allows the common mode voltage to essentially blow past the barrier and interfere with measurements, or even damage the amplifier. However, most common mode voltages are a composite of line voltages, so frequencies generally remain in the 50 to 60 Hz region with some harmonic content, well within the rejection range of most isolation amplifiers.

Chopper Amplifier

When recording biopotentials noise and drift are the two problems encountered. Noise is due to the recording device and by the patient when they move. Drift is a shift in baseline created due to various thermal effects. A DC amplifier has a shift or sudden peak in the output when the input is zero. Therefore, a chopper amplifier solves the problems of drift in DC amplifiers. The name Chop means to sample the data. The amplifier circuit samples the analogsignal.
The general diagram of a chopper amplifier is as shown below. The first block chopper accepts the DC input signal and converts them to an AC signal. The AC amplifier block amplifies the chopped AC signal.

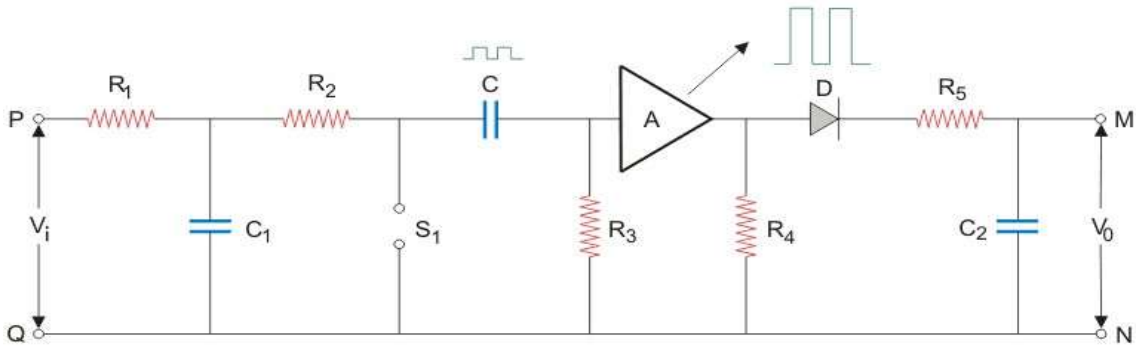
Next, in the demodulator rectifier block, an amplified chopped AC signal is converted to amplified DC signal.



Schematic Diagram of a Chopper Amplifier

Chopper amplifier is classified into two types. Mechanical and non-mechanical choppers. The chopper converts DC or low-frequency signal to high-frequency signal. An AC amplifier amplifies the modulated high-frequency signal. The amplified signal is demodulated and filtered to obtain the low frequency or DC signal.

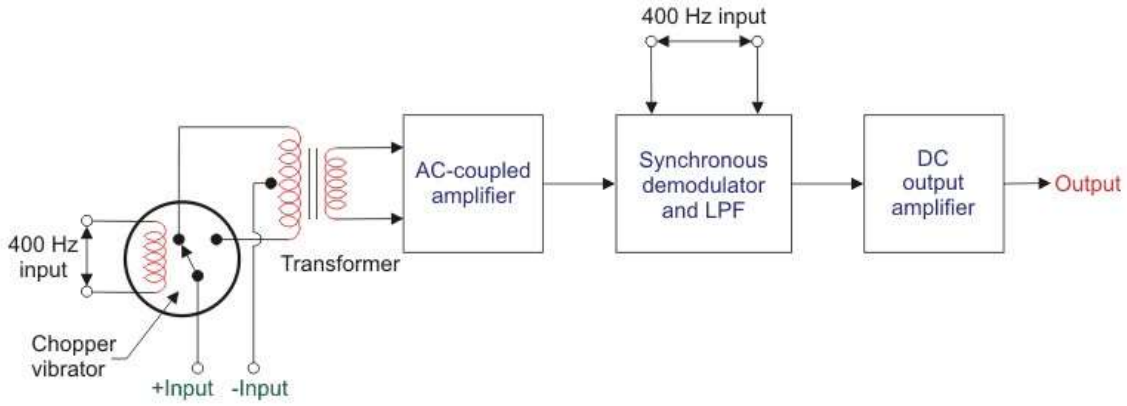
Mechanical Chopper Amplifier



From the figure, chopper S1 acts as electromagnetically operated switch or relay. _A‘ is the AC amplifier that has an input terminal and a ground terminal. _Q‘ acts as reference term. Chopper acts a switch, so it connects the amplifier input terminal alternatively to reference term Q. Consider a condition in which chopper S1 is closed. At this position, the amplifier input terminal connects to Q1. The entire circuit is short-circuited, so input voltage is zero. Now, let us consider the reverse operation when chopper S1 is open. The AC amplifier starts receiving the signal from P terminal. Finally, the amplifier input has an alternating voltage that varies between zero and input voltage. At this stage, conversion of DC signal to square wave pulse occurs with amplification. Diode _D‘ rectifies the chopped signal.

After rectification, the rectified signal is filtered and amplified. At the output terminal M and N, the amplified DC output signal occurs. Chopping or sampling rate determines the chopper response time.

Differential Chopper Amplifier



A type of chopper used for EEG measurement is a differential chopper. It has a transformer. A chopper vibrator connects the input of the transformer. The center tap of the transformer acts as one of the terminals for the input connector. The chopper switch acts as another terminal. AC coupled amplifier provides the gain. The output from this amplifier goes to filter and demodulator block. Finally, an amplified DC output signal is obtained.

Origin of Biopotentials

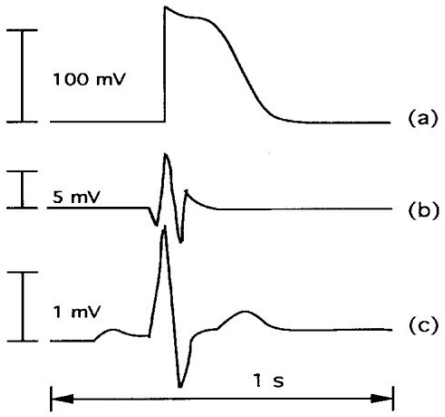
Cells transport ions across their membrane leading to ion concentration differences and therefore charge differences - hence generating a voltage.

Most cell groups in the tissues of the human body do not produce electric voltages synchronously, but more or less randomly. Thus most tissues have a resultant voltage of zero as the various random voltages cancel out.

When many cells produce voltages synchronously the resultant voltage is high enough to be measurable e.g., EMG - muscle fibre contraction, most cells of the fibre perform the same electric activity synchronously and a measurable electric voltage appears.Many organs in the human body, such as the heart, brain, muscles, and eyes, manifest their function through electric activity. The heart, for example, produces a signal called the electrocardiogram or ECG (Figure 74.1a). The brain produces a signal called an electroencephalogram or EEG (Figure 74.1b). The activity of muscles, such as contraction and relaxation, produces an electromyogram or EMG

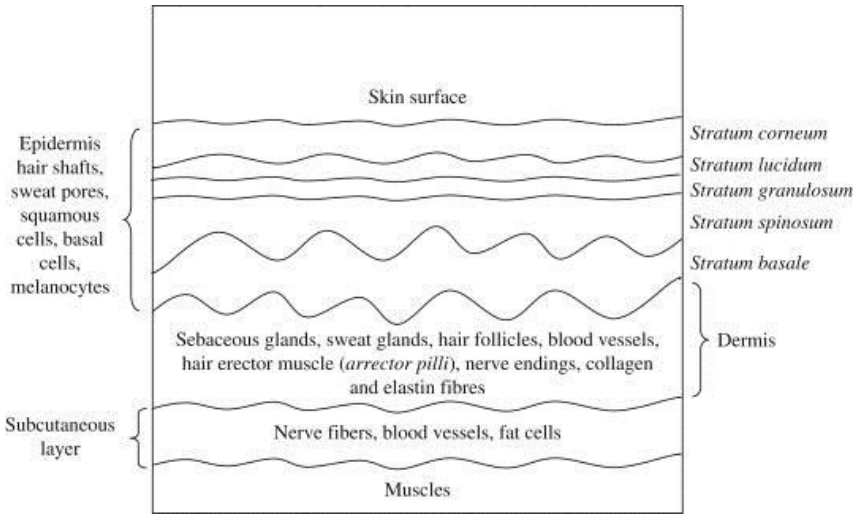
Measurements of these and other electric signals from the body can provide vital clues as to normal or pathological functions of the organs. For example, abnormal heart beats or arrhythmias can be readily diagnosed from an ECG. Neurologists interpret EEG signals to identify epileptic seizure events. EMG signals can be helpful in assessing muscle function as well as neuromuscular disorders. EOG signals are used in the diagnosis of disorders of eye movement and balance disorders. The origins of these bio potentials can be traced to the electric activity at the cellular level. The electric potential across a cell membrane is the result

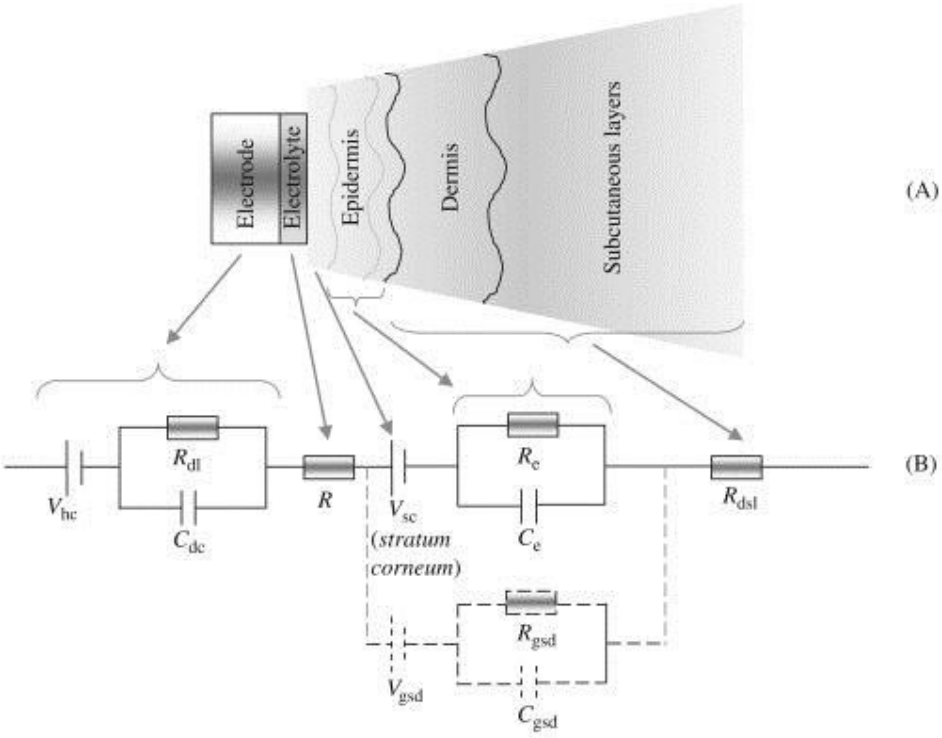
of different ionic concentrations that exist inside and outside the cell. The electrochemical concentration gradient across a semipermeable membrane results in the Nernst potential. The cell membrane separates high concentrations of potassium ion and low concentrations of sodium ions (along with other ions such as calcium in less significant proportions) inside a cell and just the opposite outside a cell. This difference in ionic concentration across the cell membrane produces the resting potential. Some of the cells in the body are excitable and produce what is called an action potential, which results from a rapid flux of ions across the cell membrane in response to an electric stimulation or transient change in the electric gradient of the cell. The electric excitation of cells generates currents in the surrounding volume conductor manifesting itself as potentials on the body.



Electrolyte Interface

The skin–electrolyte interface can also be included in the equivalent circuit that represents the biopotential measurement over the body surface. The layers organization of the skin is shown in Figure 2.13. The skin, an organ in constant renovation, is divided into three layers: epidermis, dermis, and subcutaneous layer. Epidermis has five layers and the outer one is the stratum corneum, formed mainly of dead cutaneous cells, which acts like a protection barrier against water loss, microorganisms, and sun, for instance. Stratum corneum, considered like an ion semipermeable, has high electrical resistance compared to other layers and its effect is minimized through partial removal (cleaning or abrasion).





where:

C_{dl} = Capacitance of the double layer in the metal/electrolyte interface

V_{hc} = Half-cell potential of the metal electrode

R_{dl} = Resistance of the double layer in the metal/electrolyte interface

R = Resistance of the electrolyte

V_{sc} = Potential drop, defined by Nernst equation, that results from the difference of ionic concentration between the *stratum corneum* (semipermeable membrane) and the electrolyte

C_e and R_e = Capacitance and resistance of the epidermis impedance

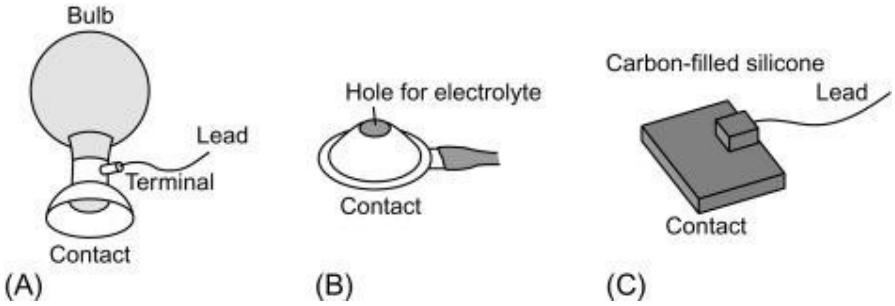
R_{dsl} = Resistance that represents dermis and subcutaneous layers (nerves, blood vessels, glands, and sweat ducts and hair follicles)

V_{gsd}, C_{gsd}, and R_{gsd} = Elements that represent glands and sweat ducts in the presence of thermal stimulus

A parallel RC circuit represents the effect of the epidermis, and therefore its impedance changes with frequency: the impedance of 1 cm2 of skin is equal to approximately 200 kΩ at 1 Hz and 200 Ω at 1 MHz. The effect of the sweat glands and ducts is omitted in the absence of thermal stimulus (dashed lines). The effect of the deeper layers produces negligible DC potential (voltage drop across *R*dsl) (Chan, 2008; Cobbold, 1974; Geddes & Baker, 1968; Webster, 2010).

Surface Electrodes

Surface electrodes are types of electrodes applied to the skin of the subject. Major applications include electrocardiography (ECG), electromyography (EMG), or electroencephalography (EEG), which are techniques for recording and evaluating the electrical activities of the heart, skeletal muscles and neurons of the brain, respectively, from the surface of the skin. Other types of electrodes are used to measure the conductance of body parts. Examples are measurements of skin conductance or transthoracic impedance. In some cases, electrodes are simple metal plates connected with a lead wire. Electrode may be made in the form of a suction cup attached with a bulb, facilitating easy attachment and relocation (see Fig. 8.2A). Commonly used for EEG measurements are cup-shaped gold electrodes with an open apex, from which electrolyte gel can be added to improve connection (Fig. 8.2B). Dry electrodes are types of electrodes that do not use electrolyte. They are typically made of silicone elastomer added with graphite powder (Fig. 8.2C). One of the most important goals for desirable surface electrodes is to obtain a lower contact impedance, which is crucial to attain high signal-to-noise ratio.



Needle Electrodes

A needle electrode inserted into the EAS can determine both its activity and its muscular quality. Sphincter denervation is followed by re innervation by neighbouring healthy axons, which can be quantified electro myographically because the recorded action potentials become polyphonic. Until the advent of AES, electromyography was the only reliable way to diagnose sphincter tears preoperatively; the needle was inserted into the suspected defect, which was confirmed if no muscular potentials could be recorded subsequently (also possible if the needle tip missed the normal muscle because of incorrect placement—easily done when insertion is blind!). Needle passes were then made circumferentially around the anus until normal potentials were encountered, thus mapping the sphincter defect. Electromyography is painful

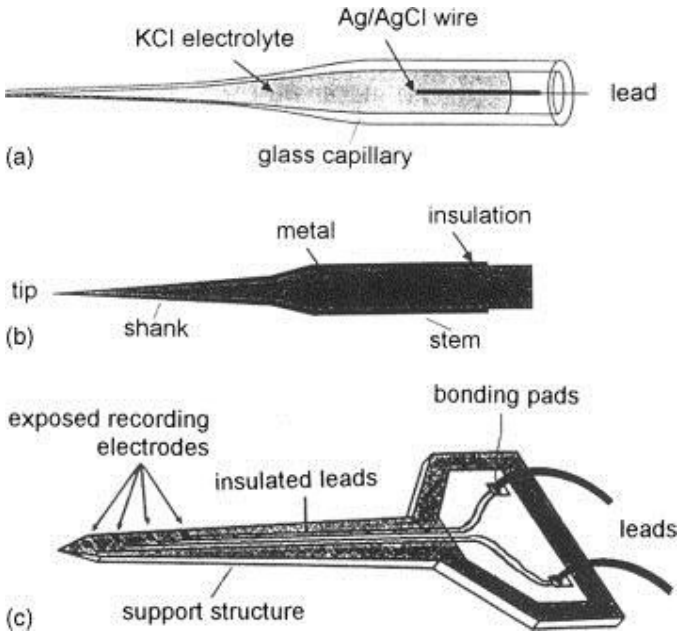
because local anesthetic interferes with recording. Fortunately, AES is superior for detecting sphincter defects when the two modalities are compared directly

Micro electrode

Microelectrode Techniques

Microelectrodes have been used extensively to determine concentration of substances of physiological importance. In the case of oxygen this has taken the form of an array of electrodes placed on the surface of the tissue or a microelectrode inserted into the tissue at a point of interest. Surface measurements provide a histogram of tissue oxygen tension over a wider field but it is a surface measurement and identification of the recording site is limited by the presence of the opaque electrode in the field. The microelectrode technique allows the investigator to place the tip at a chosen site but obtaining measurements at different sites in the same field is difficult since the electrodes must be withdrawn and calibrated after each measurement. Both methods are calibrated in vitro and the calibration must be verified after use. The microelectrode technique has been used extensively to determine perivascular and tissue PO2 . Microelectrodes have also been used to determine pH. Nitric oxide can also be measured with microelectrodes.

Microelectrodes are biopotential electrodes with an ultrafine tapered tip that can be inserted into individual biological cells. These electrodes serve an important role in recording action potentials from single cells and are commonly used in neurophysiological studies. The tip of these electrodes must be small with respect to the dimensions of the biological cell to avoid cell damage and at the same time sufficiently strong to penetrate the cell wall. Figure 10.8 illustrates the construction of three typical types of microelectrodes: glass micropipettes, metal microelectrodes, and solid-state microprobes.



MODULE-IV

ORIGIN AND DYNAMICS OF THE ECG

What is an ECG?

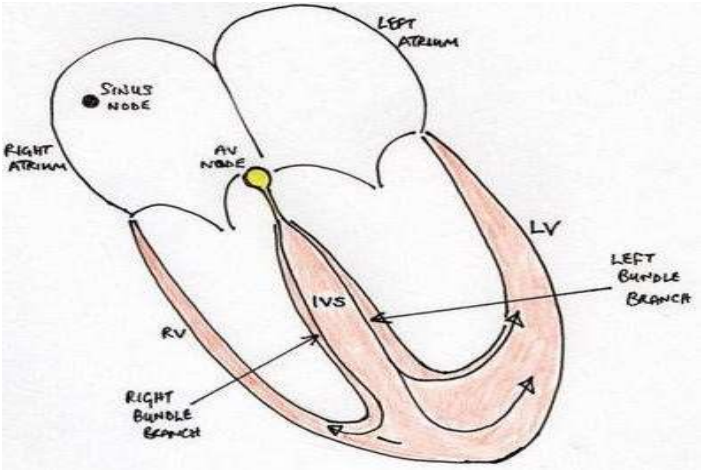
An ECG is simply a representation of the electrical activity of the heart muscle as it changes with time, usually printed on paper for easier analysis. Like other muscles, cardiac muscle contracts in response to electrical *depolarisation* of the muscle cells. It is the sum of this electrical activity, when amplified and recorded for just a few seconds that we know as an ECG.

Electrophysiology of the Heart

The normal cardiac cycle begins with spontaneous depolarisation of the sinus node, an area of specialised tissue situated in the high right atrium (RA). A wave of electrical depolarisation then spreads through the RA and across the inter-atrial septum into the left atrium (LA).

The atria are separated from the ventricles by an electrically inert fibrous ring, so that in the normal heart the only route of transmission of electrical depolarisation from atria to ventricles is through the atrioventricular (AV) node. The AV node delays the electrical signal for a short time, and then the wave of depolarisation spreads down the interventricular septum (IVS), via the bundle of His and the right and left bundle branches, into the right (RV) and left (LV) ventricles. Hence with normal conduction the two ventricles contract simultaneously, which is important in maximising cardiac efficiency.

After complete depolarisation of the heart, the myocardium must then *repolarise*, before it can be ready to depolarise again for the next cardiac cycle.



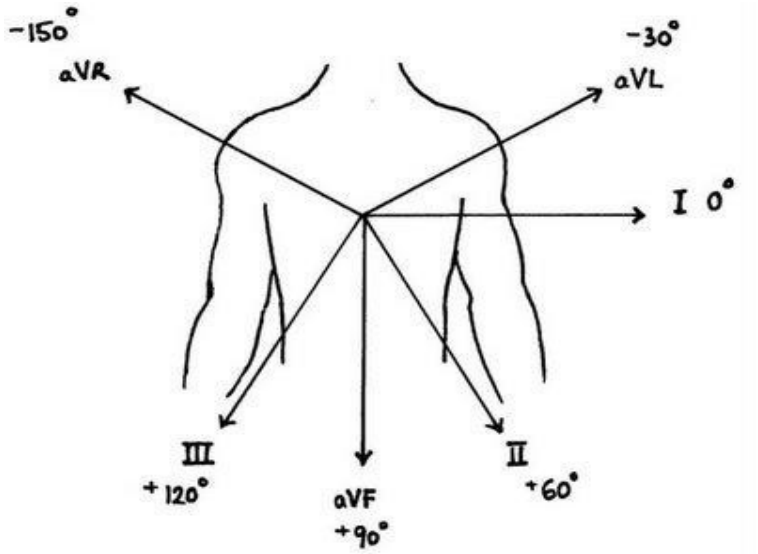
Basic electrophysiology of the heart

Electrical axis and recording lead vectors

The ECG is measured by placing a series of electrodes on the patient‘s skin – so it is known as the _surface‘ ECG.

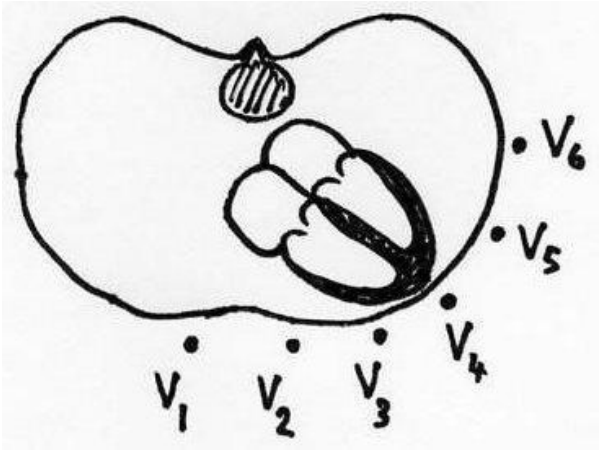
The wave of electrical depolarisation spreads from the atria down though the IVS to the ventricles. So the direction of this depolarisation is usually from the superior to the inferior aspect of the heart. The direction of the wave of depolarisation is normally towards the left due to the leftward orientation of the heart in the chest and the greater muscle mass of the left ventricle than the right. This overall direction of travel of the electrical depolarisation through the heart is known as the electrical axis.

A fundamental principle of ECG recording is that when the wave of depolarisation travels toward a recording lead this results in a positive or upward deflection. When it travels away from a recording lead this results in a negative or downward deflection.
The electrical axis is normally downward and to the left but we can estimate it more accurately in individual patients if we understand from which ‗direction' each recording lead measures the ECG.



Orientation of the limb leads showing the direction from which each lead 'looks' at the heart

By convention, we record the standard surface ECG using 12 different recording lead ‗directions,' though rather confusingly only 10 recording electrodes on the skin are required to achieve this. Six of these are recorded from the chest overlying the heart – the chest or precordial leads. Four are recorded from the limbs – the limb leads. It is essential that each of the 10 recording electrodes is placed in its correct position, otherwise the appearance of the ECG will be changed significantly, preventing correct interpretation.
The limb leads record the ECG in the coronal plane, and so can be used to determine the electrical axis (which is usually measured only in the coronal plane). The limb leads are called leads I, II, III, AVR, AVL and AVF. Figure 2 shows the relative directions from which they ‗look' at the heart. A horizontal line through the heart and directed to the left (exactly in the direction of lead I) is conventionally labelled as the reference point of 0 degrees (0 o). The directions from which other leads ‗look' at the heart are described in terms of the angle in degrees from this baseline.
The electrical axis of depolarisation is also expressed in degrees and is normally in the range from -30 0 to + 90 0. A detailed explanation of how to determine the axis is beyond the scope of this article but the principles mentioned here should help readers to understand the concepts involved.
The chest leads record the ECG in the transverse or horizontal plane, and are called V1, V2, V3, V4, V5 and V6 (see Figure 3).



Transverse section of the chest showing the orientation of the six chest leads in relation to the heart

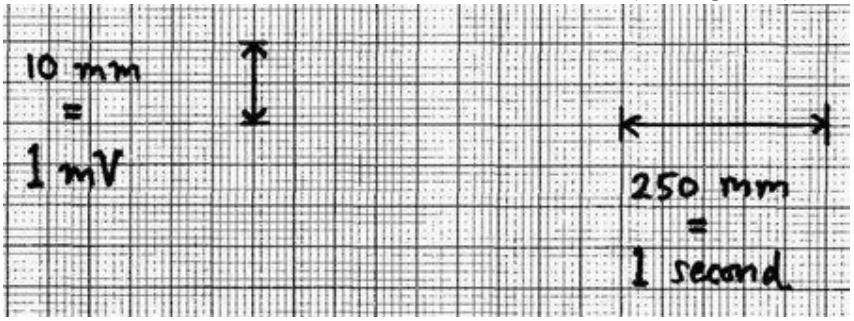
Voltage and timing intervals

It is conventional to record the ECG using standard measures for amplitude of the electrical signal and for the speed at which the paper moves during the recording.

The amplitude, or voltage, of the recorded electrical signal is expressed on an ECG in the vertical dimension and is measured in millivolts (mV). On standard ECG paper 1mV is represented by a deflection of 10 mm. An increase in the amount of muscle mass, such as with left ventricular hypertrophy (LVH), usually results in a larger electrical depolarisation signal, and so a larger amplitude of vertical deflection on the ECG.

An essential feature of the ECG is that the electrical activity of the heart is shown as it varies with time. In other words we can think of the ECG as a graph, plotting electrical activity on the vertical axis against time on the horizontal axis. Standard ECG paper moves at 25 mm per second during real-time recording. This means that when looking at the printed ECG a distance of 25 mm along the horizontal axis represents 1 second in time.

ECG paper is marked with a grid of small and large squares. Each small square represents 40 milliseconds (ms) in time along the horizontal axis and each larger square contains 5 small squares, thus representing 200 ms. Standard paper speeds and square markings allow easy measurement of cardiac timing intervals. This enables calculation of heart rates and identification of abnormal electrical conduction within the heart (see Figure 4).



Sample of standard ECG paper showing the scale of voltage, measured on the vertical axis, against time on the horizontal axis

The normal ECG

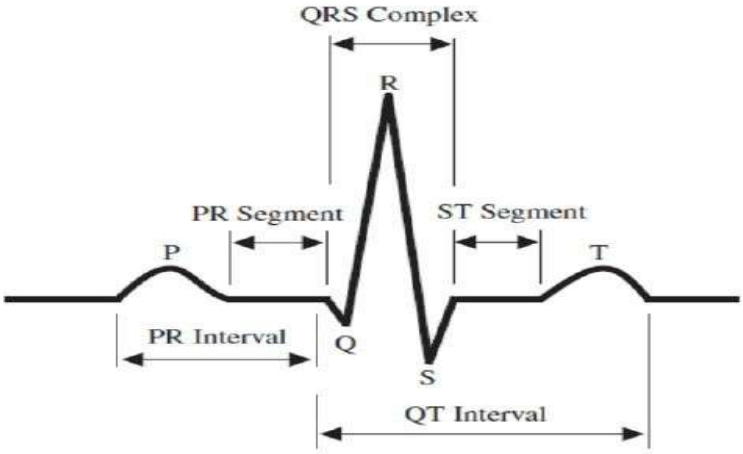
It will be clear from above that the first structure to be depolarised during normal sinus rhythm is the right atrium, closely followed by the left atrium. So the first electrical signal on a normal ECG originates from the atria and is known as the P wave. Although there is usually only one P wave in most leads of an ECG, the P wave is in fact the sum of the electrical signals from the two atria, which are usually superimposed.

There is then a short, physiological delay as the atrioventricular (AV) node slows the electrical depolarisation before it proceeds to the ventricles. This delay is responsible for the PR interval, a short period where no electrical activity is seen on the ECG, represented by a straight horizontal or _isoelectric' line.

Depolarisation of the ventricles results in usually the largest part of the ECG signal (because of the greater muscle mass in the ventricles) and this is known as the QRS complex.

- The Q wave is the first initial downward or _negative' deflection
- The R wave is then the next upward deflection (provided it crosses the isoelectric line and becomes _positive')
- The S wave is then the next deflection downwards, provided it crosses the isoelectric line to become briefly negative before returning to the isoelectric baseline.

In the case of the ventricles, there is also an electrical signal reflecting repolarisation of the myocardium. This is shown as the ST segment and the T wave. The ST segment is normally isoelectric, and the T wave in most leads is an upright deflection of variable amplitude and duration (see Figures 5 and 6).



The major waves of a single normal ECG pattern

Normal intervals

The recording of an ECG on standard paper allows the time taken for the various phases of electrical depolarisation to be measured, usually in milliseconds. There is a recognised normal range for such _intervals':

PR interval (measured from the beginning of the P wave to the first deflection of the QRS complex). Normal range 120 – 200 ms (3 – 5 small squares on ECG paper).

QRS duration (measured from first deflection of QRS complex to end of QRS complex at isoelectric line). Normal range up to 120 ms (3 small squares on ECG paper).

QT interval (measured from first deflection of QRS complex to end of T wave at isoelectric line). Normal range up to 440 ms (though varies with heart rate and may be slightly longer in females)

Heart rate estimation from the ECG

Standard ECG paper allows an approximate estimation of the heart rate (HR) from an ECG recording. Each second of time is represented by 250 mm (5 large squares) along the horizontal axis. So if the number of large squares between each QRS complex is:

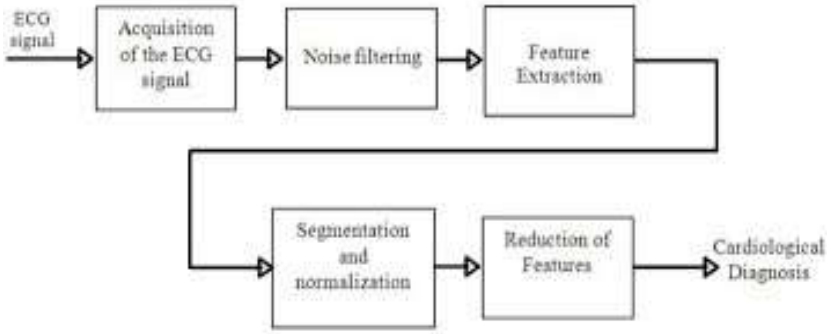
5 - the HR is 60 beats per minute.

3 - the HR is 100 per minute. 2

- the HR is 150 per minute.

The electrocardiogram (ECG) is one of the simplest and oldest cardiac investigations available, yet it can provide a wealth of useful information and remains an essential part of the assessment of cardiac patients.

With modern machines, surface ECGs are quick and easy to obtain at the bedside and are based on relatively simple electrophysiological concepts.



ORIGIN AND DYNAMICS OF THE EMG

Electromyography (EMG) is a diagnostic procedure to assess the health of muscles and the nerve cells that control them (motor neurons). EMG results can reveal nerve dysfunction, muscle dysfunction or problems with nerve-to-muscle signal transmission.

Motor neurons transmit electrical signals that cause muscles to contract. An EMG uses tiny devices called electrodes to translate these signals into graphs, sounds or numerical values that are then interpreted by a specialist.

During a needle EMG, a needle electrode inserted directly into a muscle records the electrical activity in that muscle.

A nerve conduction study, another part of an EMG, uses electrode stickers applied to the skin (surface electrodes) to measure the speed and strength of signals traveling between two or more points.

The surface electromyography (sEMG) signal is a biomedical signal that measures electrical currents generated in muscles during its contraction representing neuromuscular activities.

EMG (electromyography) records the movement of our muscles. It is based on the simple fact that whenever a muscle contracts, a burst of electric activity is generated which propagates through adjacent tissue and bone and can be recorded from neighboring skin areas.

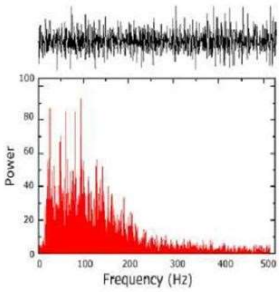
It is done if a person has signs or symptoms that may indicate a nerve or muscle disorder. Such symptoms may include: Tingling
Numbness
Muscle weakness
Muscle pain or cramping
Certain types of limb pain

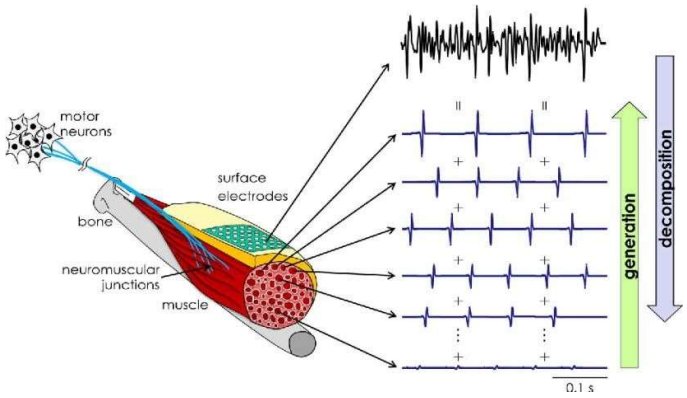
EMG results are often necessary to help diagnose or rule out a number of conditions such as:
Muscle disorders, such as muscular dystrophy or polymyositis
Diseases affecting the connection between the nerve and the muscle, such as myasthenia gravis
Disorders of nerves outside the spinal cord (peripheral nerves), such as carpal tunnel syndrome or peripheral neuropathies
Disorders that affect the motor neurons in the brain or spinal cord, such as amyotrophic lateral sclerosis or polio
Disorders that affect the nerve root, such as a herniated disk in the spine

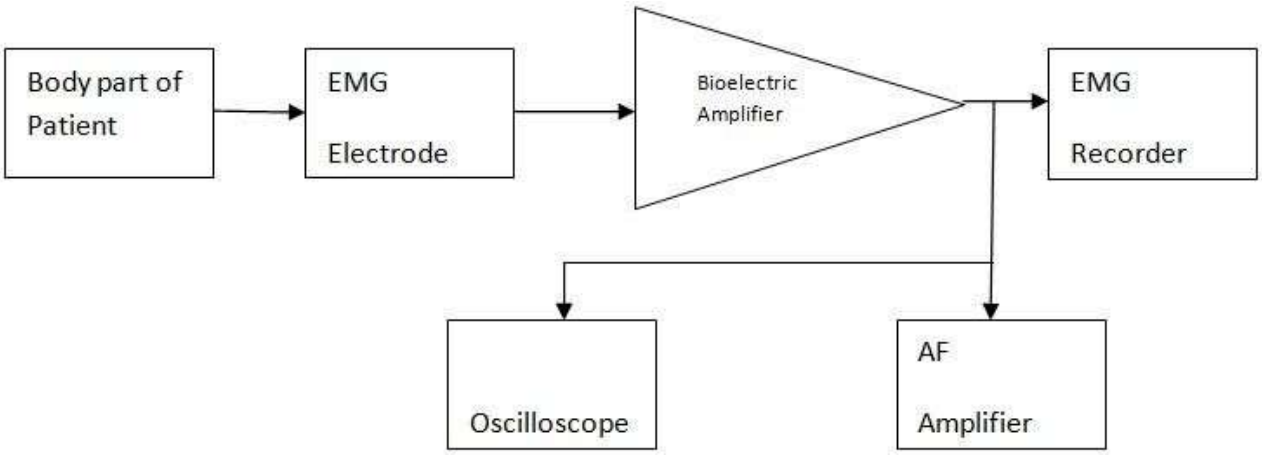
What information does EMG provide?
As EMG activity (measured in microvolts) is linearly related to the amount of muscle contraction as well as the number of contracted muscles – or in other words, the stronger the muscle contraction and the higher the number of activated muscles, the higher the recorded voltage amplitude will be.
As EMG activity is even measurable when we do not display obvious actions or even inhibit certain behaviors, EMG recordings represent an additional source of information into cognitive-behavioral processing which would be hidden based on pure observation.
There is a close coupling between muscular EMG and motor cortex EEG as reflected by significant correlations in signal features such as frequency power and phase in the (12 – 25 Hz) beta band [3, 4, 5]. This emphasizes the power of EMG recordings for monitoring the interaction of cortical and motor systems.
While EMG is clearly helpful in understanding how people move, the use of fEMG (facial electromyography, in which EMG signals are recorded from the muscles of the face), can also provide information about facial expressions.

Characteristics of EMG Signal

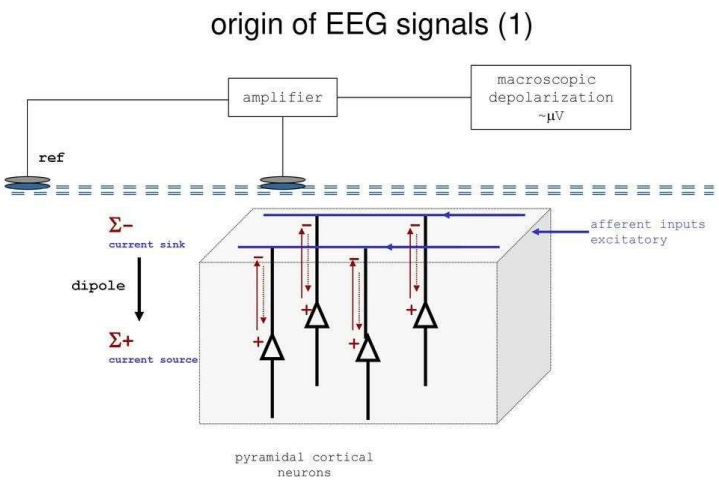
- Amplitude range:
  0 - 10 mV (+5 to -5) prior to amplification
- EMG frequency:
  range of 10 - 500 Hz
- Dominant energy:
  50 - 150 Hz
- Peak in the neighborhood of 80 - 100Hz







ORIGIN AND DYNAMICS OF THE EEG



The electroencephalogram (EEG) is a recording of the electrical activity of the brain from the scalp. The recorded waveforms reflect the cortical electrical activity. Signal intensity: EEG activity is quite small, measured in microvolts (mV).

Signal frequency: the main frequencies of the human EEG waves are:

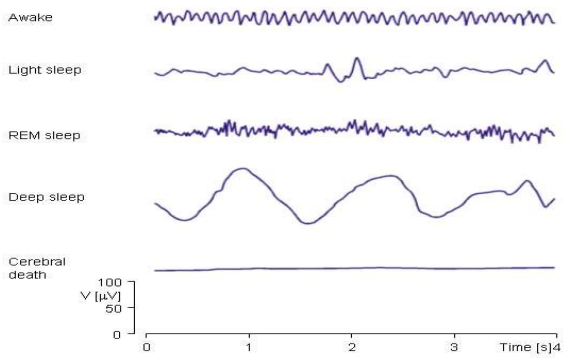
Delta: has a frequency of 3 Hz or below. It tends to be the highest in amplitude and the slowest waves. It is normal as the dominant rhythm in infants up to one year and in stages 3 and 4 of sleep. It may occur focally with subcortical lesions and in general distribution with diffuse lesions, metabolic encephalopathy hydrocephalus or deep midline lesions. It is usually most prominent frontally in adults (e.g. FIRDA - Frontal Intermittent Rhythmic Delta) and posteriorly in children e.g. OIRDA - Occipital Intermittent Rhythmic Delta).

Theta: has a frequency of 3.5 to 7.5 Hz and is classified as "slow" activity. It is perfectly normal in children up to 13 years and in sleep but abnormal in awake adults. It can be seen as a manifestation of focal subcortical lesions; it can also be seen in generalized distribution in diffuse disorders such as metabolic encephalopathy or some instances of hydrocephalus.

Alpha: has a frequency between 7.5 and 13 Hz. Is usually best seen in the posterior regions of the head on each side, being higher in amplitude on the dominant side. It appears when closing the eyes and relaxing, and disappears when opening the eyes or alerting by any mechanism (thinking, calculating). It is the major rhythm seen in normal relaxed adults. It is present during most of life especially after the thirteenth year.

Beta: beta activity is "fast" activity. It has a frequency of 14 and greater Hz. It is usually seen on both sides in symmetrical distribution and is most evident frontally. It is accentuated by sedative-hypnotic drugs especially the benzodiazepines and the barbiturates. It may be absent or reduced in areas of cortical damage. It is generally regarded as a normal rhythm. It is the dominant rhythm in patients who are alert or anxious or have their eyes open.

Activity	Frequency (HZ)	Characteristic of signals	Behavior
Delta	0.5–4	Slow wave	Sleeping
Theta	4–8	Slow wave Low frequency	Falling
Alpha	8–13	Fast wave	Relaxing
Beta	13–30	Fast wave high frequency	Psychical activity
Gamma	30–40	Fast wave high frequency	Stress mechanism

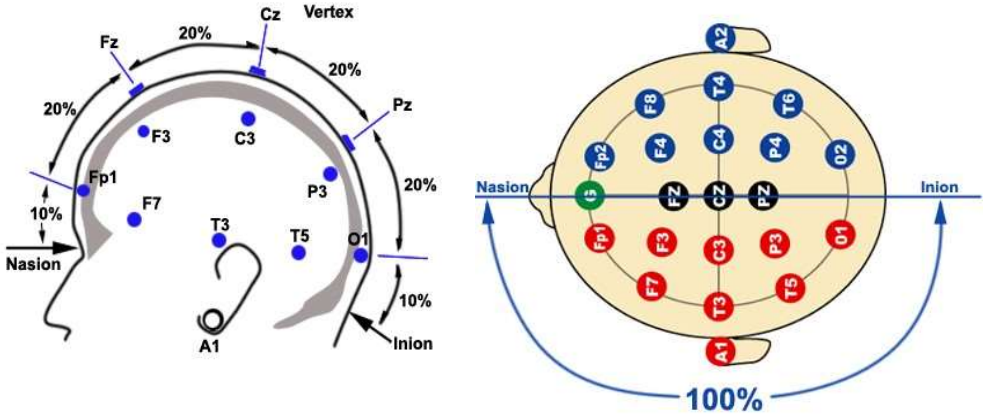


Electrode positioning (10/20 system)

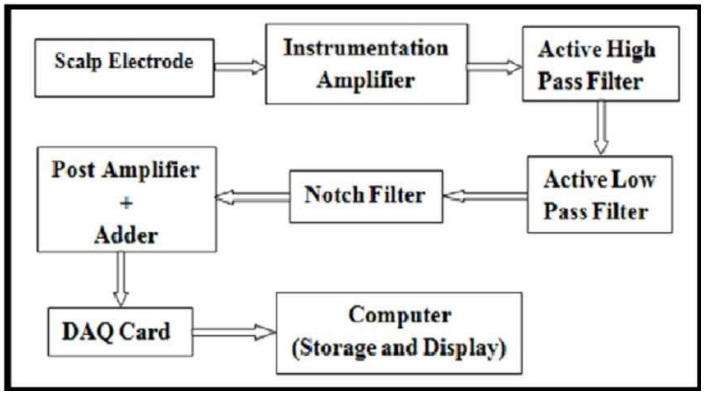
The standardized placement of scalp electrodes for a classical EEG recording has become common since the adoption of the 10/20 system. The essence of this system is the distance in percentages of the 10/20 range between Nasion-Inion and fixed points. These points are marked as the Frontal pole (Fp), Central (C), Parietal (P), occipital (O), and Temporal (T). The midline electrodes are marked with a subscript z, which stands for zero. The odd numbers are used as subscript for points over the left hemisphere, and even numbers over the right.

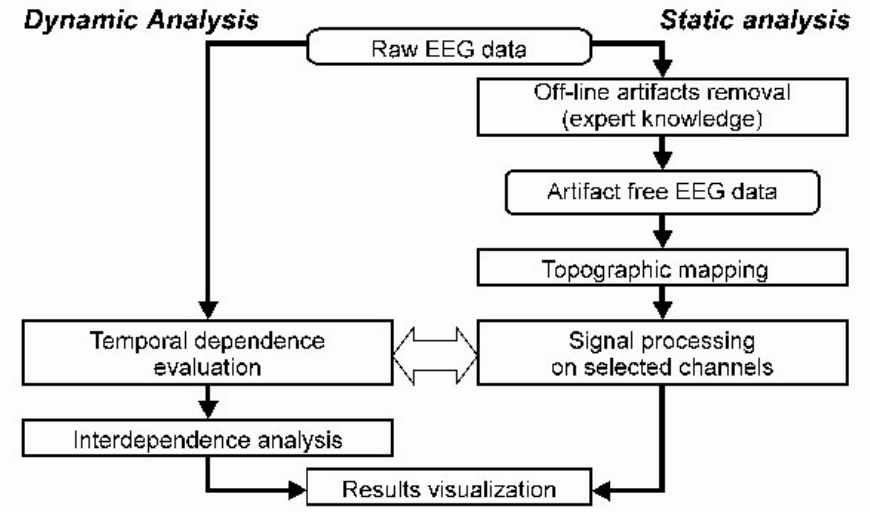
EEG montages

Montage means the placement of the electrodes. The EEG can be monitored with either a bipolar montage or a referential one. Bipolar means that you have two electrodes per one channel, so you have a reference electrode for each channel. The referential montage means that you have a common reference electrode for all the channels



10/20 System of electrode placement





SIGNAL PROCESSING

Ultimate goal of signal processing is to extract useful information from measured data
- Noise reduction and signal enhancement
- Signal conditioning
- Feature extraction
- Pattern recognition
- Classification such as diagnosis

Time Synchronous Averaging

The time-synchronous averaged signal is computed from a long and relatively periodic raw signal through synchronization, resampling, and averaging.
Time-synchronous averaging is a convenient method of background noise reduction in a spectrum of complexsignals.

Time Synchronous Averaging (TSA) is a fundamentally different process than the usual spectrum averaging that is generally used in FFT analysis. While the concept is similar, TSA results in a time domain signal with lower noise than would result with a single sample. An FFT can then be computed from the averaged time signal. The signal is sampled using a trigger that is synchronized with the signal. The averaging process gradually eliminates random noise because the random noise is not coherent with the trigger. Only the signal that is synchronous and coherent with the trigger will persist in the averaged calculation, as shown below:

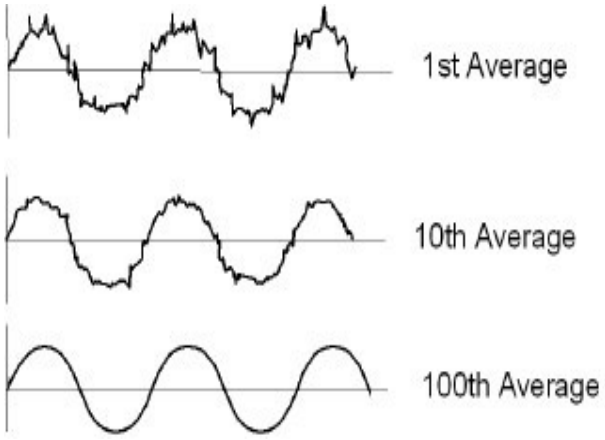


Illustration of the effect of Time Synchronous Averaging.

Traditional spectrum based averaging records a frame of data in the time domain, computes the FFT and then adds the FFT spectrum to the averaged spectrum. The time signal is discarded and then the process is repeated until the averaging number is complete. The result is a spectrum with very low noise, but if you examine each time record that is used to compute the FFT spectra, each time record will include the signal of interest plus random noise because the averaging is performed in the frequency domain, not the time domain. With TSA the result is a time domain signal with very low noise because the averaging is performed in the time

domain, not the frequency domain. In addition you can then compute an FFT of the averaged time signal resulting in a spectrum with low noise. When you compute time domain averaging on a vibration signal from a real machine, the averaged time record gradually accumulates the components of the signal that are synchronized with the trigger. Other components of the signal, such as noise and components from rotating parts of the machine, etc., are effectively averaged out. This is the only type of averaging that actually does reduce noise in the time domain.

Moving Average Filter (MA filter)

The moving average filter is a simple Low Pass FIR (Finite Impulse Response) filter commonly used for smoothing an array of sampled data/signal. It takes LL samples of input at a time and takes the average of those LL-samples and produces a single output point. It is a very simple LPF (Low Pass Filter) structure that comes handy for scientists and engineers to filter unwanted noisy component from the intended data.

As the filter length increases (the parameter LL) the smoothness of the output increases, whereas the sharp transitions in the data are made increasingly blunt. This implies that this filter has excellent time domain response but a poor frequency response.

The MA filter performs three important functions:

1) It takes LL input points, computes the average of those LL-points and produces a single output point
2) Due to the computation/calculations involved, the filter introduces a definite amount of delay
3) The filter acts as a Low Pass Filter (with poor frequency domain response and a good time domain response).

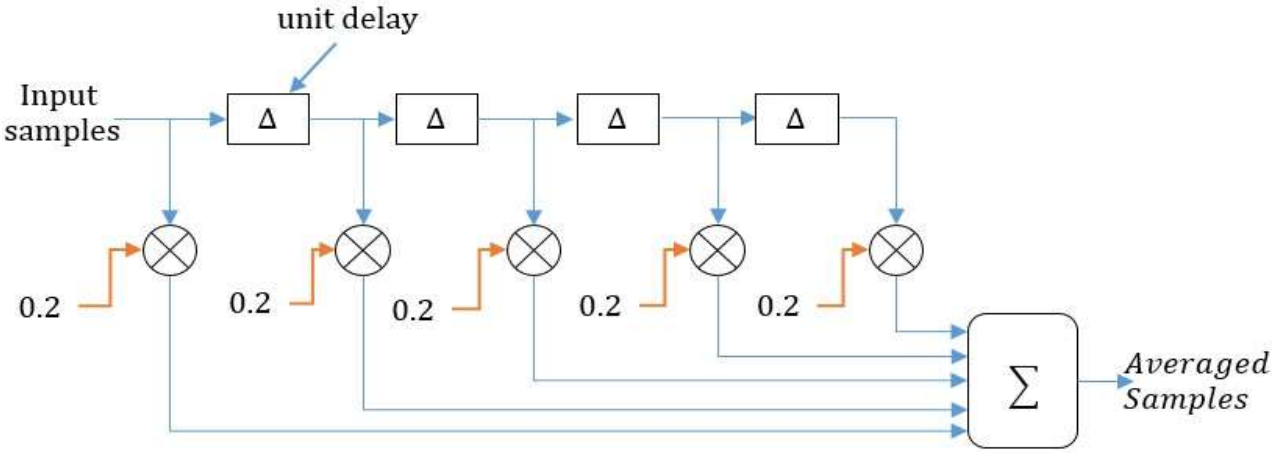
Implementation

The difference equation for a LL-point discrete-time moving average filter with input represented by the vector xx and the averaged output vector yy, is $y[n]=1L\sum k=0L-1x[n-k](1)y[n]=1L\sum k=0L-1x[n-k](1)$

For example, a 55-point Moving Average FIR filter takes the current and previous four samples of input and calculates the average. This operation is represented as shown in the Figure 1 with the following difference equation for the input output relationship in discretetime.

$y[n]=15(x[n]+x[n-1]+x[n-2]+x[n-3]+x[n-4])=0.2(x[n]+x[n-1]+x[n-2]+x[n-3]+x[n-4])(2)$

$y[n]=15(x[n]+x[n-1]+x[n-2]+x[n-3]+x[n-4])=0.2(x[n]+x[n-1]+x[n-2]+x[n-3]+x[n-4])(2)$



Discrete-time 5-point Moving Average FIR filter

The unit delay shown in the Figure is realized by either of the two options:
Representing the input samples as an array in the computer memory and processing them Using D-Flip flop shift registers for digital hardware implementation. If each discrete value of the input xx is represented as a 1212-bit signal line from ADC (analog to digital converter), then we would require 4 sets of 12-Flip flops to implement the 55-point moving average filter shown in Figure 1.

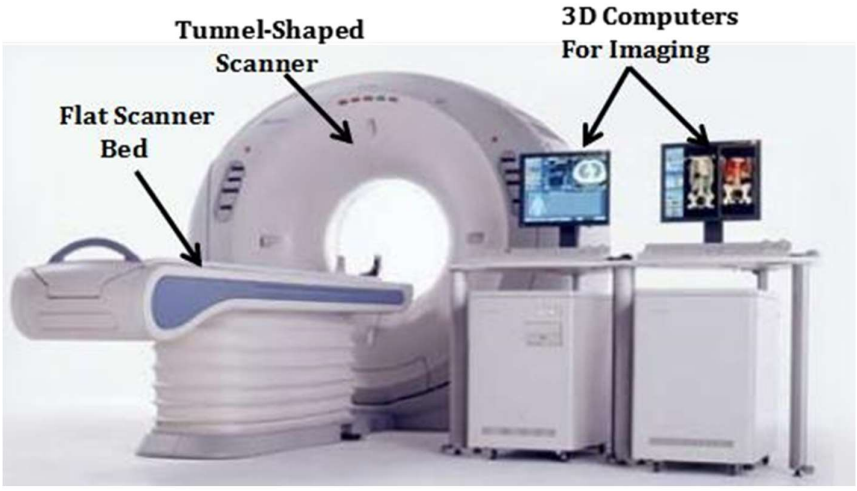
MODULE -V COMPUTED TOMOGRAPHY/CT SCAN

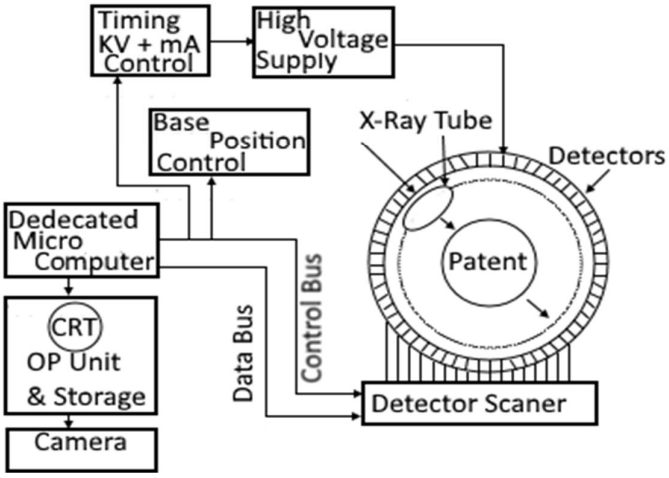
Computed tomography (CT) is a diagnostic imaging test used to create detailed images of internal organs, bones, soft tissue and blood vessels. The cross-sectional images generated during a CT scan can be reformatted in multiple planes, and can even generate threedimensional images which can be viewed on a computer monitor, printed on film or transferred to electronic media. CT scanning is often the best method for detecting many different cancers since the images allow your doctor to confirm the presence of a tumor and determine its size and location. CT is fast, painless, noninvasive and accurate. In emergency cases, it can reveal internal injuries and bleeding quickly enough to help save lives.
A CT scan is a test that uses x-rays and a computer to create detailed pictures of the inside of your body. It takes pictures from different angles. The computer puts them together to make a 3 dimensional (3D) image.
CT (or CAT) stands for computed (axial) tomography.
We usually have a CT scan in the x-ray (radiology) department as an outpatient. A radiographer operates the scanner. The whole appointment can take up to an hour and a half depending on which part of your body they are scanning.

We might have a CT scan:

- to diagnose a range of conditions including cancer
- to help work out where the cancer is, how close it is to nearby organs and how big it is - this can help your doctors decide about whether you need further tests or what treatment you need
- to check how well treatment is working

- as part of your follow up after treatment





How does CT work?

- Unlike a conventional x-ray—which uses a fixed x-ray tube—a CT scanner uses a motorized x-ray source that rotates around the circular opening of a donut-shaped structure called a gantry. During a CT scan, the patient lies on a bed that slowly moves through the gantry while the x-ray tube rotates around the patient, shooting narrow beams of x-rays through the body. Instead of film, CT scanners use special digital x-ray detectors, which are located directly opposite the x-ray source. As the xrays leave the patient, they are picked up by the detectors and transmitted to a computer. Each time the x-ray source completes one full rotation, the CT computer uses sophisticated mathematical techniques to construct a 2D image slice of the patient. The thickness of the tissue represented in each image slice can vary depending on the CT machine used, but usually ranges from 1-10 millimeters. When a full slice is completed, the image is stored and the motorized bed is moved forward incrementally into the gantry. The x-ray scanning process is then repeated to produce another image slice. This process continues until the desired number of slices is collected. Image slices can either be displayed individually or stacked together by the computer to generate a 3D image of the patient that shows the skeleton, organs, and tissues as well as any abnormalities the physician is trying to identify. This method has many advantages including the ability to rotate the 3D image in space or to view slices in succession, making it easier to find the exact place where a problem may be located.

Preparation for a CT scan

- Some CT scans need special preparation beforehand.
- For most scans, you have a drink or an injection of contrast medium, or both. This is a dye that shows up body tissues more clearly on the scan. You have the injection through a small thin tube (cannula) in your arm. The tube is left in place until after your scan, in case you have any problems after having the injection. CT scans of the abdomen

If you are having a CT scan of your abdomen, you might be asked:

- to drink a liquid contrast medium some time before the scan
- to drink more of the liquid contrast or water in the x-ray department
- not to eat or drink after midnight the night before the scan (this is for a CT scan of the inside of the large bowel, called CT colonography)

Usually the contrast medium is given by injection and also as a drink. This helps to show up the gut (digestive system) more clearly in the scan.

CT scans of the head

For some brain scans, you might have an injection of the contrast medium dye beforehand to make the scan clearer. CT scans of the chest

You might have an injection of the contrast medium during the scan. This is to help show up the tissues close to the area containing cancer, for example, blood vessels. It may help to show whether cancer can be removed with surgery or not. Pelvic CT scans

If you are having a CT scan of the pelvis, you might be asked:

- not to eat or drink for some time before the scan
- to have an injection of contrast medium

Occasionally, for a rectal scan, you need to have an enema of contrast medium. This shows up on the x-ray and makes the outline of the bowel show up more on the scan. It might make you constipated. Your first couple of bowel motions will be white, but there are no other side effects.

CT colonography

You might have a very detailed scan of the bowel called a CT colonography (or virtual colonoscopy).

If you're having one of these, you will be asked to clear your bowel by taking strong laxatives, drinking a special liquid with meals and following a special diet about 2 days before the test. Your doctor or nurse will tell you about this. You might also have a medicine to slow down the normal movement of your bowel. This movement (called peristalsis) can change the scan and make it more difficult to read.

Possible risks

A CT scan is a safe test for most people but like all medical tests it has some possible risks. Your doctor and radiographer make sure the benefits of having the test outweigh these risks.

Allergic reaction

Rarely, people have an allergic reaction to the contrast medium. This most often starts with weakness, sweating and difficulty breathing. Tell your radiographer immediately if you feel unwell.

Bruising and swelling

People might get a small bruise around the area where they put the needle in.

There's a risk that the contrast medium will leak outside the vein. This can cause swelling and pain in your hand or arm but it‘s rare.

Kidney problems

There is a small risk that the contrast medium can affect your kidneys. Your radiographer checks your most recent blood test results before your scan to make sure your kidneys are working well. **Radiation**

Exposure to radiation during a CT scan can slightly increase your risk of developing cancer in the future. Talk to your doctor if this worries you.

Pregnancy

Pregnant women should only have CT scans in emergencies. Contact the department as soon as you can before the scan if you are pregnant or think that you might be.

POSITRON EMISSION TOMOGRAPHY - COMPUTED TOMOGRAPHY (PET/CT)

Positron emission tomography (PET) uses small amounts of radioactive materials called radiotracers, a special camera and a computer to help evaluate your organ and tissue functions. By identifying body changes at the cellular level, PET may detect the early onset of disease before it is evident on other imaging tests.

Discuss any recent illnesses, medical conditions, medications you're taking and allergies – especially to contrast material. You will likely be told not to eat anything and to drink only water several hours before your scan. Leave jewelry at home and wear loose, comfortable clothing. You may be asked to wear a gown.

Positron emission tomography, also called PET imaging or a PET scan, is a type of nuclear medicine imaging.

Nuclear medicine is a branch of medical imaging that uses small amounts of radioactive material to diagnose and determine the severity of or treat a variety of diseases, including many types of cancers, heart disease, gastrointestinal, endocrine, neurological disorders and other abnormalities within the body. Because nuclear medicine procedures are able to pinpoint molecular activity within the body, they offer the potential to identify disease in its earliest stages as well as a patient‘s immediate response to therapeutic interventions. Nuclear medicine imaging procedures are noninvasive and, with the exception of intravenous injections, are usually painless medical tests that help physicians diagnose and evaluate medical conditions. These imaging scans use radioactive materials called radiopharmaceuticals or radiotracers.

Radiotracers are molecules linked to, or "labeled" with, a small amount of radioactive material that can be detected on the PET scan. They are designed to accumulate in cancerous tumors or regions of inflammation. They can also be made to bind to specific proteins in the body. The most commonly used radiotracer is F-18 fluorodeoxyglucose, or FDG, a molecule similar to glucose. Cancer cells may absorb glucose at a higher rate, being more metabolically active. This higher rate can be seen on PET scans, and that allows your doctor to identify disease before it may be seen on other imaging tests. FDG is just one of many radiotracers in use or in development for a variety of conditions throughout the body. Depending on the type of nuclear medicine exam, the radiotracer is either injected into the body, swallowed or inhaled as a gas and eventually accumulates in the organ or area of the body being examined. Radioactive emissions from the radiotracer are detected by a special camera or imaging device that produces pictures and provides molecular information.

In many centers, nuclear medicine images can be superimposed with computed tomography (CT) or magnetic resonance imaging (MRI) to produce special views, a practice known as

image fusion or co-registration. These views allow the information from two different exams to be correlated and interpreted on one image, leading to more precise information and accurate diagnoses.

In addition, manufacturers are now making single photon emission computed tomography/computed tomography (SPECT/CT) and positron emission tomography/computed tomography (PET/CT) units that are able to perform both imaging exams at the same time. An emerging imaging technology, but not readily available at this time is PET/MRI.

A PET scan measures important body functions, such as blood flow, oxygen use, and sugar (glucose) metabolism, to help doctors evaluate how well organs and tissues are functioning. CT imaging uses special x-ray equipment, and in some cases a contrast material, to produce multiple images or pictures of the inside of the body. These images can then be interpreted by a radiologist on a computer monitor. CT imaging provides excellent anatomic information.

Today, almost all PET scans are performed on instruments that are combined PET and CT scanners. The combined PET/CT scans provide images that pinpoint the anatomic location of abnormal metabolic activity within the body. The combined scans have been shown to provide more accurate diagnoses than the two scans performed separately.

What are some common uses of the procedure?

PET and PET/CT scans are performed to:

- detect cancer.
- determine whether a cancer has spread in the body.
- assess the effectiveness of a treatment plan, such as cancer therapy.
- determine if a cancer has returned after treatment.
- determine blood flow to the heart muscle.
- determine the effects of a heart attack, or myocardial infarction, on areas of the heart.
- identify areas of the heart muscle that would benefit from a procedure such as angioplasty or coronary artery bypass surgery (in combination with a myocardial perfusion scan).
- evaluate brain abnormalities, such as tumors, memory disorders, seizures and other central nervous system disorders.
- map normal human brain and heart function.

What does the equipment look like?

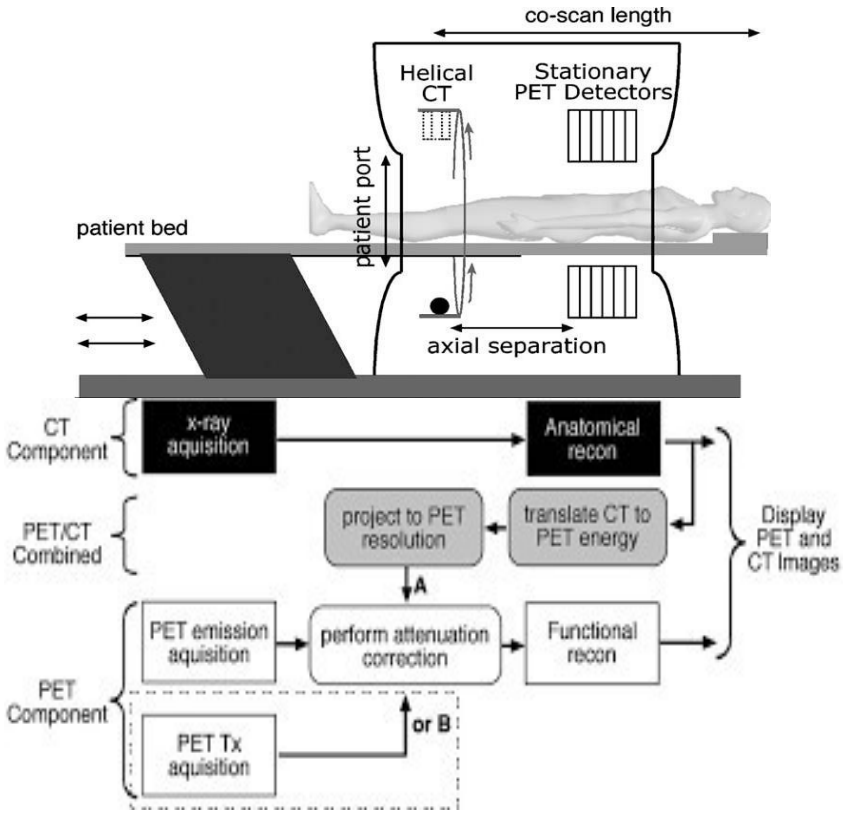
- A PET scanner is a large machine with a round, donut shaped hole in the middle, similar to a CT or MRI unit. Within this machine are multiple rings of detectors that record the emission of energy from the radiotracer in your body.
- The CT scanner is typically a large, box-like machine with a hole, or short tunnel, in the center. You will lie on a narrow examination table that slides into and out of this tunnel. Rotating around you, the x-ray tube and electronic x-ray detectors are located opposite each other in a ring, called a gantry. The computer workstation that processes the imaging information is located in a separate control room, where the technologist operates the scanner and monitors your examination in direct visual contact and usually with the ability to hear and talk to you with the use of a speaker and microphone.
- Combined PET/CT scanners are combinations of both scanners and look similar to both the PET and CT scanners.
- A computer aids in creating the images from the data obtained by the gamma camera.

- How does the procedure work?

- With ordinary x-ray examinations, an image is made by passing x-rays through the patient's body. In contrast, nuclear medicine procedures use a radioactive material, called a radiopharmaceutical or radiotracer, which is injected into the bloodstream, swallowed or inhaled as a gas. This radioactive material accumulates in the organ or area of your body being examined, where it gives off a small amount of energy in the form of gamma rays. Special cameras detect this energy, and with the help of a computer, create pictures offering details on both the structure and function of organs and tissues in your body.
- Unlike other imaging techniques, nuclear medicine imaging exams focus on depicting physiologic processes within the body, such as rates of metabolism or levels of various other chemical activity, instead of showing anatomy and structure. Areas of greater intensity, called "hot spots," indicate where large amounts of the radiotracer have accumulated and where there is a high level of chemical or metabolic activity. Less intense areas, or "cold spots," indicate a smaller concentration of radiotracer and less chemical activity.

How is the procedure performed?

- Nuclear medicine imaging is usually performed on an outpatient basis, but is often performed on hospitalized patients as well.
- Subject will be positioned on an examination table. If necessary, a nurse or technologist will insert an intravenous (IV) catheter into a vein in your hand or arm.
- Depending on the type of nuclear medicine exam you are undergoing, the dose of radiotracer is then injected intravenously, swallowed or inhaled as a gas.
- Typically, it will take approximately 60 minutes for the radiotracer to travel through your body and to be absorbed by the organ or tissue being studied. You will be asked to rest quietly, avoiding movement and talking.
- You may be asked to drink some contrast material that will localize in the intestines and help the radiologist interpreting the study.
- Subject will then be moved into the PET/CT scanner and the imaging will begin. You will need to remain still during imaging. The CT exam will be done first, followed by the PET scan. On occasion, a second CT scan with intravenous contrast will follow the PET scan. The actual CT scanning takes less than two minutes. The PET scan takes 20-30 minutes.
- Total scanning time is approximately 30 minutes.
- Depending on which organ or tissue is being examined, additional tests involving other tracers or drugs may be used, which could lengthen the procedure time to three hours. For example, if you are being examined for heart disease, you may undergo a PET scan both before and after exercising or before and after receiving intravenous medication that increases blood flow to the heart.
- When the examination is completed, you may be asked to wait until the technologist checks the images in case additional images are needed. Occasionally, more images are obtained for clarification or better visualization of certain areas or structures. The need for additional images does not necessarily mean there was a problem with the exam or that something abnormal was found, and should not be a cause of concern for you.
- If you had an intravenous line inserted for the procedure, it will usually be removed unless you are scheduled for an additional procedure that same day that requires an intravenous line.



Benefits

- Nuclear medicine examinations provide unique information—including details on both function and anatomic structure of the body that is often unattainable using other imaging procedures.
- For many diseases, nuclear medicine scans yield the most useful information needed to make a diagnosis or to determine appropriate treatment, if any.
- A nuclear medicine scan is less expensive and may yield more precise information than exploratory surgery.
- By identifying changes in the body at the cellular level, PET imaging may detect the early onset of disease before it is evident on other imaging tests such as CT or MRI.

The benefits of a combined PET/CT scanner include:

- greater detail with a higher level of accuracy; because both scans are performed at one time without the patient having to change positions, there is less room for error.
- greater convenience for the patient who undergoes two exams (CT & PET) at one sitting, rather than at two different times. **Risks**
- Because the doses of radiotracer administered are small, diagnostic nuclear medicine procedures result in relatively low radiation exposure to the patient, acceptable for diagnostic exams. Thus, the radiation risk is very low compared with the potential benefits.
- Nuclear medicine diagnostic procedures have been used for more than five decades, and there are no known long-term adverse effects from such low-dose exposure.

- The risks of the treatment are always weighed against the potential benefits for nuclear medicine therapeutic procedures. You will be informed of all significant risks prior to the treatment and have an opportunity to ask questions.
- Allergic reactions to radiopharmaceuticals may occur but are extremely rare and are usually mild.
- Injection of the radiotracer may cause slight pain and redness which should rapidly resolve.

What are the limitations of Positron Emission Tomography – Computed Tomography (PET/CT)?

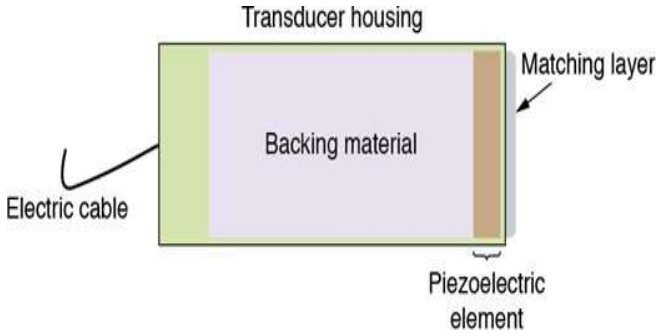
- Nuclear medicine procedures can be time consuming. It can take several hours to days for the radiotracer to accumulate in the body part of interest and imaging may take up to several hours to perform, though in some cases, newer equipment is available that can substantially shorten the procedure time.
- The resolution of structures of the body with nuclear medicine may not be as high as with other imaging techniques, such as CT or MRI. However, nuclear medicine scans are more sensitive than other techniques for a variety of indications, and the functional information gained from nuclear medicine exams is often unobtainable by other imaging techniques.

- Test results of diabetic patients or patients who have eaten within a few hours prior to the examination can be adversely affected because of altered blood sugar or blood insulin levels.
- Because the radioactive substance decays quickly and is effective for only a short period of time, it is important for the patient to be on time for the appointment and to receive the radioactive material at the scheduled time. Thus, late arrival for an appointment may require rescheduling the procedure for another day.
- A person who is very obese may not fit into the opening of a conventional PET/CT unit.

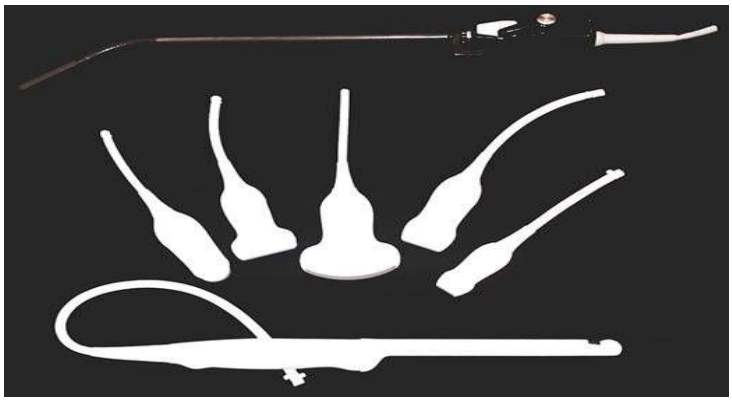
ULTRASOUND

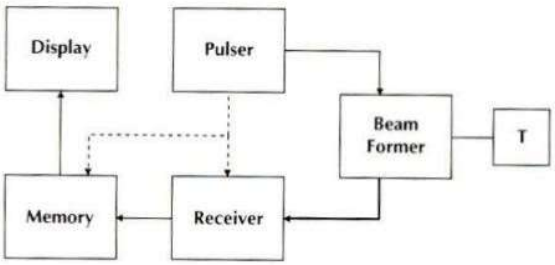
Any ultrasound system has three basic components: a transducer, or probe; the processing unit, including the controls; and the display. The transducer consists of the piezoelectric material (active element) within a nonconductive housing, which may consist of one solitary element or several hundred elements (known as an array). A piezoelectric material has the property of converting mechanical energy (ultrasound vibrations) into electrical energy, and vice versa. In an ultrasound transducer, the electrical excitation impulse is transmitted to the piezoelectric element, and the returning echoes are then converted into electrical signals by the element and

transmitted to the processing unit via a shielded cable for further image processing. The thickness of the piezoelectric element determines the center frequency of the transducer (multiple elements allow for a range of frequencies in a single transducer). Backing material absorbs excess vibration of the received signal (dampening) and its impedance should closely match that of the active element to optimize resolution. To minimize energy loss at the face of the transducer, a matching layer is incorporated of a material with an acoustic impedance somewhere in between that of the piezoelectric material and the tissue under investigation (in medical applications). The thickness of this matching layer should be half that of the element so that waves reflected within the matching layer remain in phase when they exit the layer.



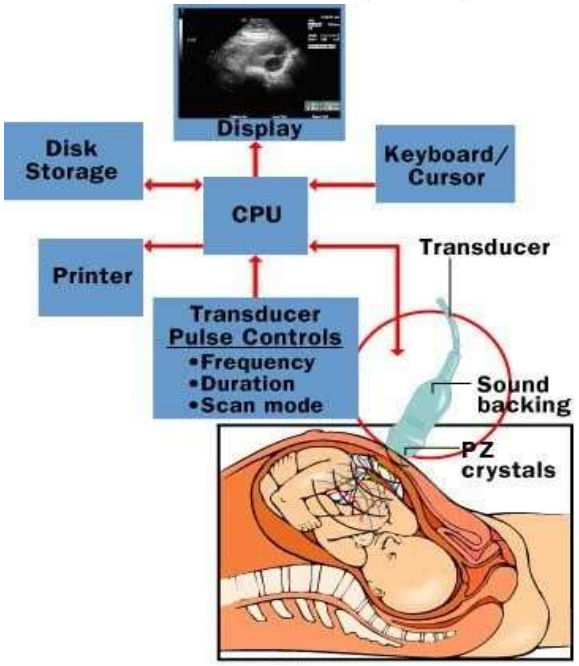
Ultrasound transducers can be divided into two basic types: mechanical and electronic. Mechanical probes contain one or multiple piezoelectric elements that physically oscillate to scan a region of interest, resulting in the classic sector scan image. These are the least expensive type of transducer to manufacture, but scanning and processing options are limited. In the case of radial scanning, such as that employed for endocavity (endorectal, endoanal, and esophageal) applications, rigid mechanical transducers are utilized for a 360 degree view of the luminal structure. They are available in a variety of sizes, frequencies, and lengths





Pulser : The pulser produces electric pulses that drives the transducer (T) through the beam former. It also includes a clock that determines the pulse repetition frequency (PRF) and synchronizes the various components of the instrument.

Beam former : The beam former performs all the tasks necessary for beam steering,transmit focusing, dynamic aperture and any other additional timing requirements for phase arrays.



In ultrasound, the following events happen:

1. The ultrasound machine transmits high-frequency (1 to 5 megahertz) sound pulses into your body using a probe.
2. The sound waves travel into your body and hit a boundary between tissues (e.g. between fluid and soft tissue, soft tissue and bone).
3. Some of the sound waves get reflected back to the probe, while some travel on further until they reach another boundary and get reflected.
4. The reflected waves are picked up by the probe and relayed to the machine.
5. The machine calculates the distance from the probe to the tissue or organ (boundaries) using the speed of sound in tissue (5,005 ft/s or1,540 m/s) and the time of the each echo's return (usually on the order of millionths of a second).

6. The machine displays the distances and intensities of the echoes on the screen, forming a two dimensional image like the one shown below.
7. In a typical ultrasound, millions of pulses and echoes are sent and received each second. The probe can be moved along the surface of the body and angled to obtain various views.

4 Types of Ultrasound Imaging

2D Ultrasound

The most common and type of ultrasound picture is a series of flat, two-dimensional cross section images of the scanned tissue. Referred to simply as 2d ultrasound, this mode of scanning is still standard for many diagnostic and obstetric situations after a half-century of use.

3D Ultrasound

In recent years, 2d ultrasound images have also been projected into three-dimensional representations. This is achieved by scanning tissue cross sections at many different angles and reconstructing the data received into a three-dimensional image. A common use for 3d ultrasound pictures is to provide a more complete and realistic image of a developing fetus.

4D Ultrasound Imaging

By updating 3d ultrasound images in rapid succession, sonographers can also create 4d ultrasound pictures. In the 4d ultrasound, the fourth dimension, time, adds movement and creates the most realistic representation of all.

In some cases, 3d and 4d ultrasound pictures may reveal abnormalities not readily seen using 2d ultrasound. For expectant mothers and family members, the ability to see realistic images of an unborn baby in the uterus can be rewarding and heartwarming although the medical community in general cautions against performing ultrasound tests solely for this purpose.

Doppler Ultrasound

Evaluating blood flow as it moves through blood vessels is a common component of many of the types of ultrasound. While traditional 2d ultrasound and its three-dimensional offshoot show internal tissues and structures, a different kind of ultrasound is required to evaluate blood flow and pressure within a blood vessel. A Doppler ultrasound analysis bounces highfrequency sound waves off blood cells in motion and records changes in frequency of the sound waves as they echo back to the transducer probe. It then converts this data into a visual representation of how fast and in what direction blood is flowing. Doppler ultrasound is an indispensable diagnostic tool in all areas of ultrasound testing and is preferable in many cases to X-ray angiography because it does not require injecting the patient with contrasting dye. Three types of Doppler ultrasound are currently in use in addition to routine grayscale imaging. Of these, color Doppler uses a wide choice of colors to visualize blood flow measurements and embed them within a conventional 2d ultrasound of tissues and structures. This provides a more pronounced representation of blood flow speed and direction than is the case with traditional grayscale images. Power Doppler provides color imaging of more sensitive and detailed blood flow measurements than regular color Doppler does. It can sometimes even achieve images in situations not accessible with color Doppler. However, power Doppler is limited in another way because it cannot indicate the direction in which blood is flowing. Like conventional and color Doppler, spectral Doppler can scan to determine both blood flow and direction but displays this data in graphic form rather than with grayscale or color images.

NUCLEAR MAGNETIC RESONANCE (NMR)

Nuclear magnetic resonance is defined as a condition when the frequency of the rotating magnetic field becomes equal to the frequency of the processing nucleus. If ratio frequency energy and a, magnetic field are simultaneously applied to the nucleus, a condition as given by the equation $v = \gamma H0/2\pi$ is met. The system at this condition is said to be in resonance [v — frequency of radiation associated with transition from one state to the other; γ = proportionality constant and H0 = magnetic field]‘.

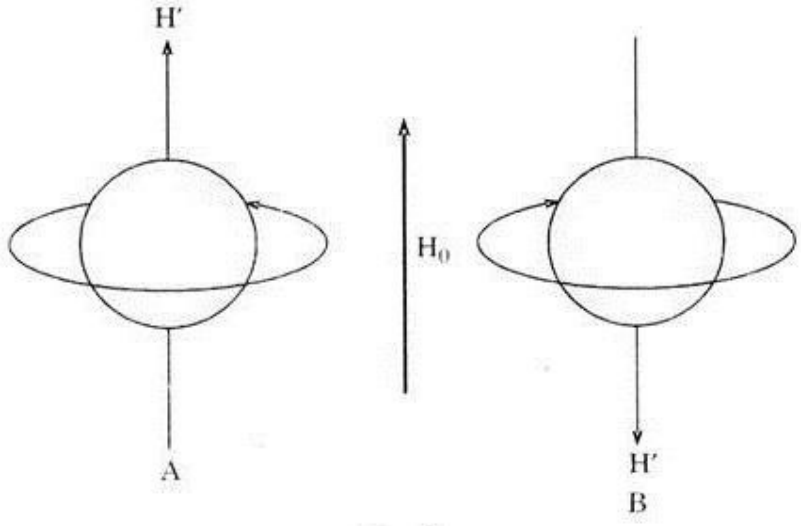
Principle of NMR:

The principle of nuclear magnetic resonance is based on the spins of atomic nuclei. The magnetic measurements depend upon the spin of unpaired electron whereas nuclear magnetic resonance measures magnetic effect caused by the spin of protons and neutrons. Both these nucleons have intrinsic angular momenta or spins and hence act as elementary magnet. The existence of nuclear magnetism was revealed in the hyper fine structure of spectral lines. If the nucleus with a certain magnetic moment is placed in the magnetic field, we can observe the phenomenon of space quantization and for each allowed direction there will be a slightly different energy level.

Theory of NMR:

The hydrogen nucleus or protons can be regarded as a spinning positively charged unit and so it will generate a tiny magnetic field HO along its spinning axis (as shown in figure 1). Now if this nucleus is placed in an external magnetic field H0, it will naturally line up either parallel A or antiparallel B to the direction of external field. The A will be more stable, being of lower energy.

The energy difference AE between two states will be absorbed or emitted as the nucleus flips from one orientation to the other.



Then

AE = hv

where v = a radiation frequency and h = Planck‘s constant

If correct frequency is applied to the sample containing hydrogen nuclie and sample is placed in the external field HQ, then low energy nuclie A will absorb AE = hv, and flips to B. Thus on flipping back down, they remit hv as a radiation signal which is picked up by the instrument.

In other words, if both radio frequency and magnetic field are simultaneously applied to the nucleus, transition from lower to higher level will occur when equation (1) will be equal to (2).

$\Delta E = \partial hH/2\pi$ … (1)

$\Delta E = hv$ … (2) or $v = \delta H/2\pi$ … (3) δ = Gyromagnctic ratio, a constant characteristic of a particular nucleus.

Where ΔE = energy difference between two spin states, h = Planck's constt, v = frequency of resonance absorption, H = strength of applied magnetic field at nucleus. The system at this condition is said to be in resonance and hence the name nuclear magnetic resonance. The observed value of H is therefore a function of molecular environment of proton affording the signal.

(1) Relaxation Process:

Relaxation processes are defined as different types of radiation-less transitions by which a nucleus in an upper spin slate returns to a lower spin state.

Generally there are two types of relaxation processes:

(a) Spin-spin Relaxation:

It is affected by mutual exchange of spins by two processing nuclei in close proximity to each other.

(b) Spin Lattice Relaxation (lattice term refers to frame work of molecules containing the precessing nuclei):

This process maintains an excess of nuclei in a lower state, which is the essential basic condition for the observation of nuclear resonance phenomenon.

In a NMR spectroscopy the sharp resonance lines are observed for stales of extended excitation, and broad lines are observed for short-lived excited stales. Both the processes, spin-spin relaxation and spin lattice relaxation contribute to he width of a spectral line.

(2) Condition of Resonance Signals:

The atoms like O^{16} and C_{12} which have even number of protons and neutrons have no magnetic moment and hence refuse to give resonance signals. While atoms such as P21, F19, which have odd number of protons and even numbers of neutrons, if any, generate nuclear magnetic moments and —hence give resonance signals.

(3) Units of NMR:

The nuclear magnetic resonance values are expressed in any of three ways:

(a) δ-the reference compound be quoted (δ denotes that chemical shift is independent of oscillator frequency).

(b) Cps — the reference compound must be quoted and the oscillator frequency given. (c) τ-TMS (tetra methylsilane) or DSS (2, 2 dimethyl-2 silapentane-5 sulphonate) is assumed independent of both oscillator frequency and reference compound.

Nuclear Magnetic Resonance Spectrometers:

The basic elements of a typical n.m.r. spectrometer consist of the main parts;

(1) A magnet with strong, stable homogeneous field. The field must be constant over the area of the sample.

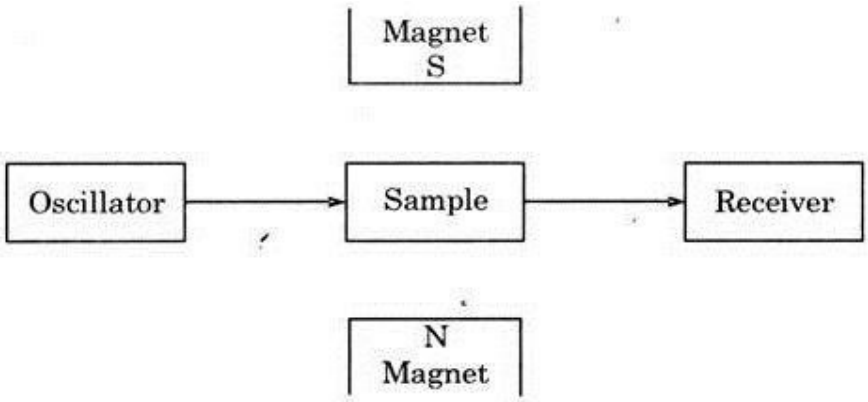
(2) A radio frequency oscillator (transmitter) connected to coil which transmits energy to the sample in a direction perpendicular to the magnetic field.

(3) A sample container, usually a glass tube spun by an air driven turbine to average the magnetic field over the sample dimensions.

(4) A radio frequency receiver connected to a coil encircling the sample. The two coils are perpendicular to each other and to the magnetic field.
(5) A read out system. The other supporting parts are— consisting of an amplifier, recorder and additional components for increasing sensitivity, accuracy or convenience.
(6) A sweep generator which supplies a variable d-c current to a secondary magnet so that the total applied magnetic field can be varied (swept) over a limited range.

Experimental Technique:
Always a dilute solution is analysed. The compound to be studied is generally mixed with a solvent like CC14 or etramclhyl silane and the dilute solution is filled in a tube.
Now when a sample under investigation is placed in the magnetic field and subjected to rf field of oscillator then at particular combinations of the oscillator frequency and field strength, the rf. energy is absorbed by certain nuclei and an rf. signal is picked up by the detector.

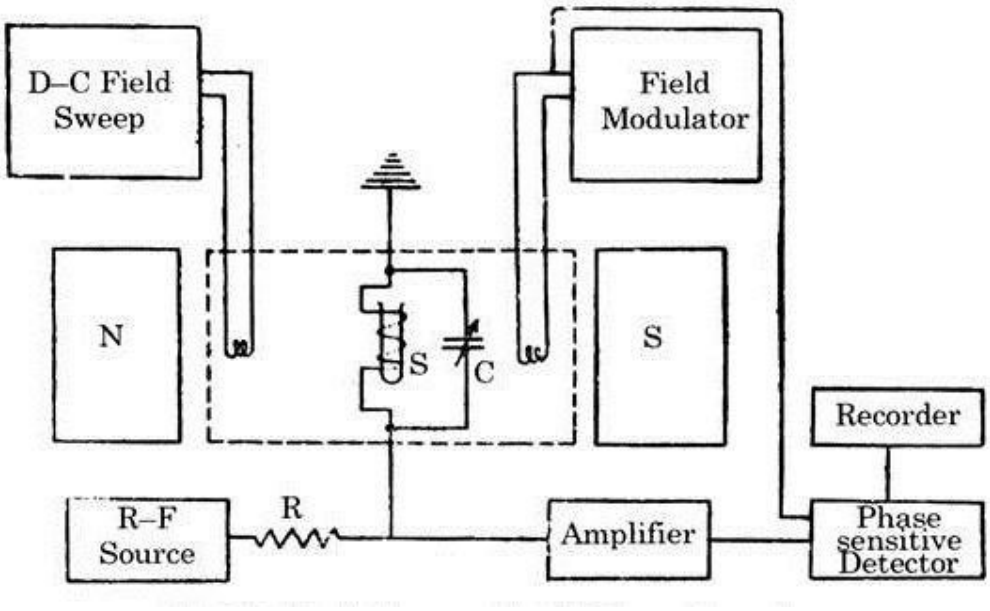
Two ways have been employed in NMR experiments for getting the desired particular combinations:
(i) In one way, the magnetic field remains constant and radio frequency is varied.



Simple Line of NMR

(ii) In second, the radio frequency remains unchanged and magnetic field is varied till resonance conditions are obtained and there is detectable absorption by the nucleus.

Instrument:
The block diagram for a sample NMR spectrometer is shown in the Fig below:



In block diagram, the blocks labelled N and S represent the poles of the large HO magnet, which is generally an electromagnet operated through a stabilized power supply. A field of up-to 1400 gauss and a pole of about 1.75 — 1.8 inch is necessary for high resolution spectra. The frequency and field strength are related to each other by Larmor condition.

$v = \gamma H0/2\pi$

[This equation represents the condition of resonance.]

where HO = magnetic field,

v = is the frequency of radiation associate with transition from one state to another. It is generally known as Larmor frequency, γ = proportionality constant or gyromagnetic ratio.

Experimental Parameter (Chemical shift):

The most important molecular parameter determined by NMR is the chemical shift. The chemical shift is defined as a measure of the resonance frequency of the nuclei in a given chemical environment.

The magnitude of the chemical shift is proportional to the strength of applied field and is caused by the circulations of surrounding electrons about the protons. The chemical shift parameter 6 is defined $\delta = (Hr - Hs)/Hr \times 106$ ppm where Hr and Hs are field strengths corresponding to resonance for a particular nucleus in the sample (Hs) and reference (Hr).

But as spectra are usually calibrated in cycles per second (cps), the equation can be written as:

$\delta = \Delta v \times 106/$Oscillator frequency (cps)

where Δv = Difference in absorption frequencies of the sample and the reference in cps; oscillator frequency is the characteristic of the instrument: For a 60 MHz instrument, the oscillator frequency is 60 × 106 cps.

The factor 106 has been included for convenience.

Units:

The units of 5, is expressed as parts per million (ppm). The tetra methyl silane (TMS) is generally taken as acceptable standard (because of low boiling point 27°C).

If the compound has a symmetrical structure, each proton is identical to all others and is found in an identical electronic environment which gives a very high shielding. As a result, TMS gives a single sharp resonance line.

Chemical shift is also designated by τ where $\tau = 10 - \delta$.

The standard (CH3)4Si protons appear between 0 on 5 scale and 10 on τ scale.

Measurement of Chemical Shift:

In fact the measurement of chemical shift gives information about the various types of magnetic environments. The chemical shift in simple molecules is fairly characteristics and may be used for analysis and characterization.

Factors which influence δ:

Actually the chemical shift parameter 8 is a function of electron density around the nucleus as the electrons are directly involved in the diamagnetic shielding which acts to attenuate the applied magnetic field.

Hence following factors are responsible for influencing its value:

(a) Specific solvent,
(b) Bulk diamagnetic susceptibility effect,
(c) Temperature (only when change in temperature causes changes in some type of association equilibrium or changes in amplitude of torsional vibrations),
(d) Electron density,
(e) Inductive effect,
(f) Vander Waal deshielding, and (g) Hydrogen bonding.

Interpretation of NMR Spectrum:

The number spectrum gives several kinds of information:

(1) The number of signals (peaks) tells us how many kinds of protons (protons with different chemical environments) are present in a molecule.
(2) The position (chemical shift) of the signal informs about the bonding environment of each proton.
(3) The area under each signal tells us how many protons of each kind are in the molecule.
(4) All hydrogens with identical environments in a molecule have same chemical shift, e.g., (a) all the three protons of a methyl CH3; (b) the protons of a methylene — CH2; (c) one identical.
(5) Protons on heteroatoms (H—S, H —N, H—O etc.) show highly variable chemical shifts and sometimes broad peaks.
(6) Hydrogen on different carbons yields the same absorptional signal if they are structurally indistinguishable.
(7) Sometimes a proton exhibits an absorption signal which is split into several peaks because of coupling with its neighbouring protons. In such cases a coupling constant J is calculated.
(8) The number of peaks (N) into which a proton signal is split equals one more than the number of vicinal protons (n) (number of equivalent neighbours causing splitting):

$N = n + 1$

N = 2 (one vicinal H) = doublet (d)
= 3 (two vicinal H‘s) = triplet (t) =
4 (three vicinal H‘s) = quartet (q).

Example:

Spectrum of-isomers—dimethyl ether and ethanol.

The low resolution spectra of isomers dimethyl ether and ethanol are shown in figures 4 (a) and (b). The spectrum of dimethyl ether shows only one signal because all 6H atoms are equivalent. The 3H atoms in a given CH3 group are indistinguishable, as are the two CH3groups.
The spectrum of ethanol has three signals-one each for CH3, CH2 and OH protons. The relative areas under the peak for the ethanol are 3:2:1 for CH3, CH2, and OH groups respectively. CH2 signal is far away than CH3 signal because of electron withdrawing effect of two adjacent atoms.

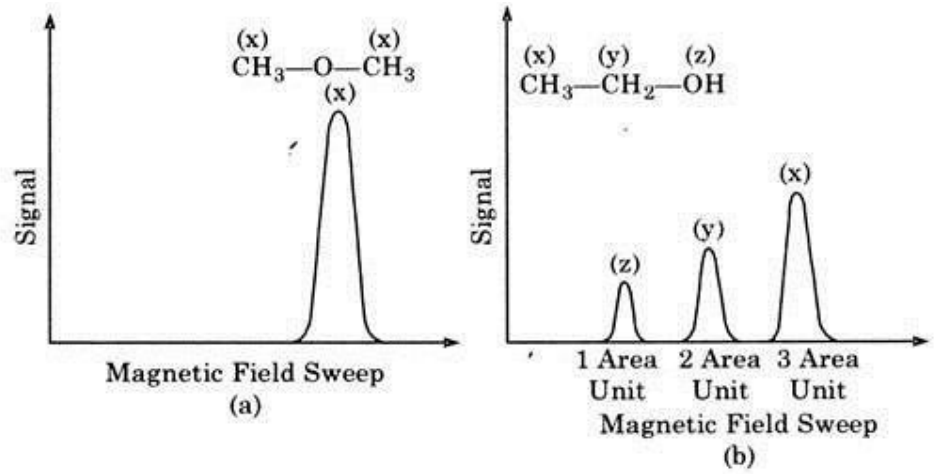


Fig. 31. Low resolution NMR spectnim of (a) dimethyl ether CII_3OCH_3; (b) eihanol CH_3CH_2OH.

In a high resolution NMR spectrum of ethyl alcohol (CH3—CH2—OH), the methyl peak is associated with two peaks, white methylene and OH are associated with four and three peaks respectively.
The three equivalent methyl protons are split into a triplet (1 + 2) by two equivalent methyl protons. Similarly two equivalent methylene protons are split into a quartet (1 + 3) by three equivalent methyl protons.

Applications of N.M.R. Spectroscope:
(1) Quantitative Analysis:
The area of peak is directly proportional to the number of nuclei responsible for that peak. Thus the concentration of species can be determined directly by making use of signal area per proton. The signal area per proton can easily be calculated by use of a known concentration of an internal standard.
Similarly, (he concentration of new species formed during the reaction can also be calculated from the spectrum of parent compound.
(2) Qualitative Analysis:
The qualitative analysis of the compound can easily be made by knowing:
(i) Chemical shift 8 values of hydrogen containing groups,
(ii) The presence of particular functional group, (iii) The relative position of these groups and (iv) The relative number of nuclei in these groups.
Nuclear Magnetic Double Resonance (NIVIDR):
When two oscillating magnetic fields are simultaneously applied to the sample, the experiment is called double resonance, double irradiation, or spin decoupling. In the usual nuclear magnetic double resonance experiment, a strong rf. field H2 is used to irradicate the sample while a weak

rf. field H1 induces the transitions to be observed. We can sweep the magnetic field holding HI and H2 constant.

Electron Paramagnetic resonance (EPR):

The electron paramagnetic resonance (EPR) differs from NMR principally because in that the frequencies of electron resonance occur in microwave region for magnetic fields of the order of several thousand gauss. Therefore EPR spectrometer uses such components as Klystrons, wave guides and resonance cavities for the sample.

EPR method is applicable whenever the compound displays at least one unpaired electron, i.e., in free radicals, crystalline and amorphous solids subjected to irradiation or containing transition element ions and rare earths had some chelates. The other different examples are metals, odd molecules, graphite‘s and impurities in semiconductors.