BIOMEDICAL INSTRUMENTATION

UNIT II

Biomedical instrumentation

- *application of knowledge and technologies - to solve problems related to living biological systems.*
- *involves diagnosis, treatment and prevention of disease in human.*
- *an expanding field.*
- *involves measurement of biological signals like ECG, EMG, or any electrical signals generated in the human body.*
- *helps physicians to diagnose the problem and provide treatment.*
- *To measure biological signals and to design a medical instrument, concepts of electronics and measurement techniques are needed.*

BIOPOTENTIAL ELECTRODES

- *A medical instrument performs a specific function on a biological system*
- *The function may be the exact measurement of physiological parameters like blood pressure, velocity of the blood flow, action potentials of the heart muscles, temperature, pH value of the blood and rates of change of these parameters*

BIOPOTENTIAL ELECTRODES

- *In physiological systems, the measureable parameters cover a wide range.*
- *The living system imposes special constraints on the instrumentation*
- *The specification must meet the requirements of the living system*
- *The design must be sufficiently flexible to accommodate the factor of biological variability*
- *Biomedical measuring devices should cause minimal disturbance to normal physiological function and are to be used with safety instrumentation*

DESIGN OF MEDICAL INSTRUMENT

- *Factors to be considered:*
- *Accuracy – closeness – approaching true value; degree of conformity to the true value of the quantity under measurement*
- *Frequency response – response to various frequency components present in the physiological signal*
- *Hysteresis – mechanical friction present in an analog indicating meter can cause the movement of the indicating needle to lag behind corresponding changes in the measured variable. Needle should be selected from the perfect elastic material*

DESIGN OF MEDICAL INSTRUMENT

- *Electrical isolation - between subject, on which the measurements are made. Ground is necessary for reasons of electrical safety to avoid any interference between different instruments used simultaneously*
- *Linearity – degree to which variations in the output of an instrument follow input variations; essential to get accurate values*
- *Sensitivity – ability of the instrument to detect even a very small change; also expressed in resolution, minimum variation that can be accurately measured*
- *Signal to noise ratio – should be very high to get reliable information*

DESIGN OF MEDICAL INSTRUMENT

- *Simplicity – to eliminate human errors*
- *Stability – ability of that instrument to produce constant output for the given input*
- *Precision – measure of the reproducibility of the measurements*
- *Higher precision and good calibration are necessary to achieve accurate results*

COMPONENTS OF THE BIO-MEDICAL INSTRUMENT SYSTEM

which are used to investigate the pH values and
the body fluids and to count blood cells in the blood samples.

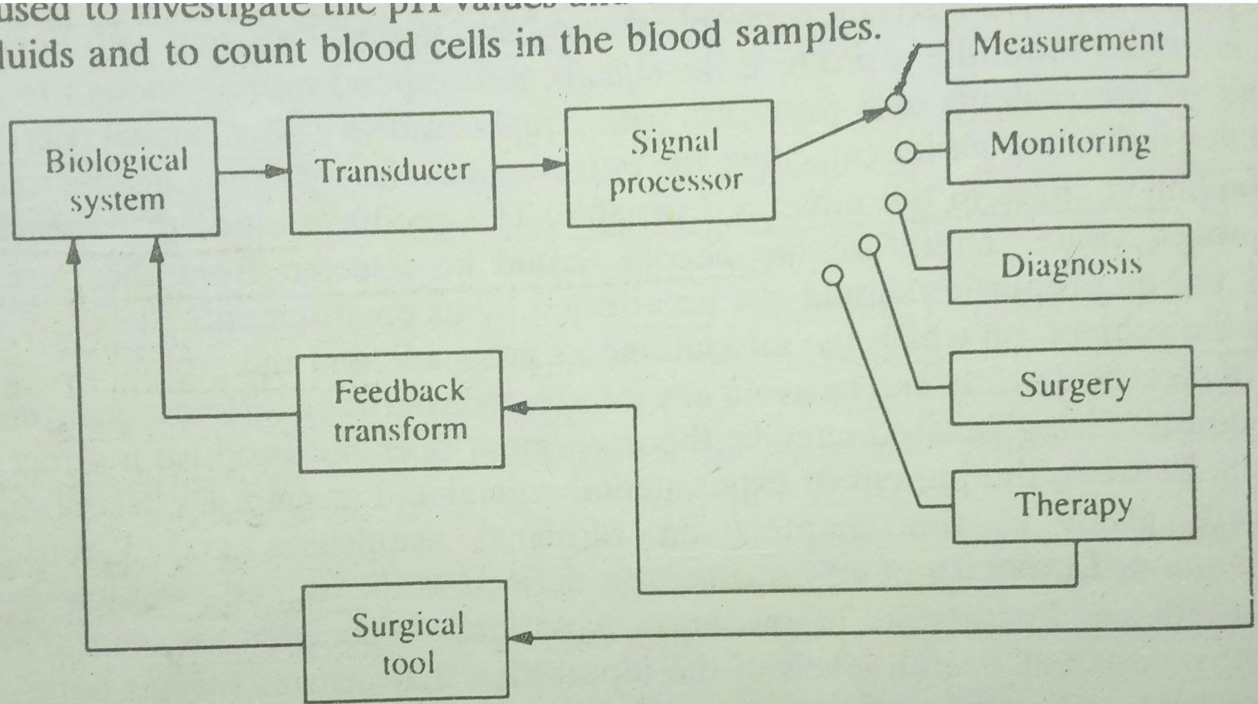
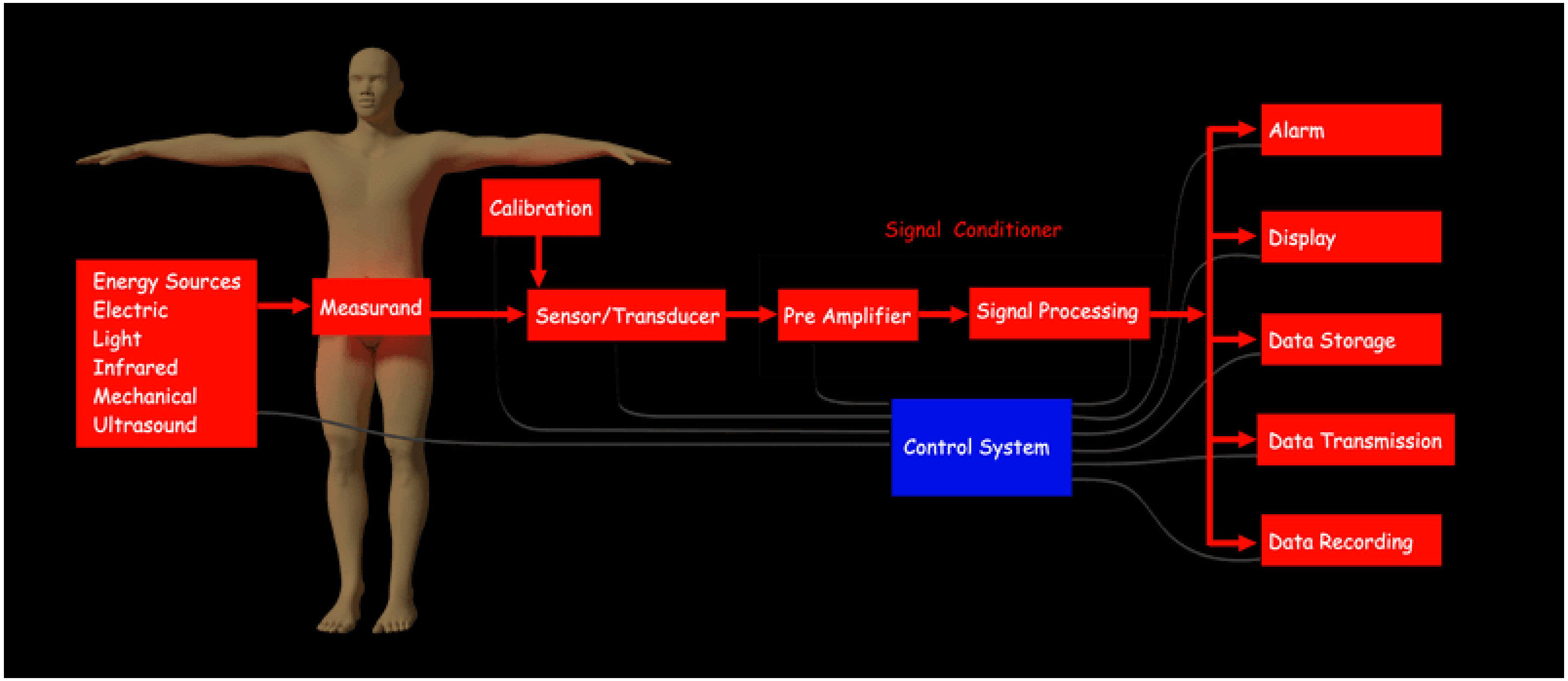


Fig.2.1. Block diagram of a generalized bio-medical instrument system


Energy Sources
Electric
Light
Infrared
Mechanical
Ultrasound
Measurand
Calibration
Sensor/Transducer
Signal Conditioner
Pre Amplifier
Signal Processing
Control System
Alarm
Display
Data Storage
Data Transmission
Data Recording

- *Human body acts as the source for measurand, and it generates bio-signals. Example: body surface or blood pressure in the heart*

COMPONENTS OF THE BIO-MEDICAL INSTRUMENT SYSTEM

- *Clinical laboratory instruments – used to investigate the pH values and concentration of various radicals present in the body fluids*
- *To count the blood cells in the blood samples*
- *Each switch position connects an instrument for measurement*
- *For monitoring, diagnosis, therapy and surgery with the signal processor*

COMPONENTS OF THE BIO-MEDICAL INSTRUMENT SYSTEM

- *Transducer – device capable of converting one form of energy or signal to another – output is always an electrical signal*
- *For example, the piezoelectric signal which converts mechanical vibrations into the electrical signal.*
- *Acts as an impedance matching device between the biological system and the signal processor*
- *Transforms the physiological signal like temperature, pressure or biopotential into a form that can be read by the signal processor*

COMPONENTS OF THE BIO-MEDICAL INSTRUMENT SYSTEM

- *Signal Processor – amplifies, modifies, or changes the electrical output of the transducer – to run the recording or display devices*
- *Signal conditioning equipment - improves the sensitivity of instruments.*
- *Type of signal processing depends upon the function of the instrument system*
- *In therapy – it must feedback the signal to the biological system through the feedback transform*
- *In surgery – a surgical tool, like electrosurgical knife and laser*

BIOMEDICAL INSTRUMENTS

ELECTRODES

- *Employed to pick up the electrical signals of the body*
- *Pair of electrodes play the role of a transducer*
- *Amplifier has to be designed – to accommodate the characteristics of electrodes*
- *Type of electrode – depends on anatomical location of bioelectric event and dimensions of the bioelectric generator*

ELECTRODES

- *Electrical characteristics of the electrodes specify the type of preamplifier*
- *For microelectrodes, many restrictions on the input impedance of the amplifier*
- *Amplifier – have large impedances, high resistance and low capacitance input circuits – need to transfer the bioelectric event to the amplifying system*

Bio Potential Electrodes

- *If electrode has same material as cation, then this material gets oxidized and enters the electrolyte as a cation a nd electrons remain at the electrode and flow in the external circuit.*
- *Electrode – Electrolyte Interface*

General Ionic Equations

- $C \leftrightarrow C^{n+} + ne^-$
- $A^{m-} \leftrightarrow A + me^-$

Bio Potential Electrodes

- *If electrode has same material as cation, then this material gets oxidized and enters the electrolyte as a cation and electrons remain at the electrode and flow in the external circuit.*
- *If anion can be oxidized at the electrode to form a neutral atom, one or two electrons are given to the electrode*
- *The dominating reaction can be inferred from the following:*
- *Current flow from electrode to electrolyte : Oxidation (Loss of e-)*
- *Current flow from electrolyte to electrode : Reduction (Gain of e-)*

Bio Potential Electrodes

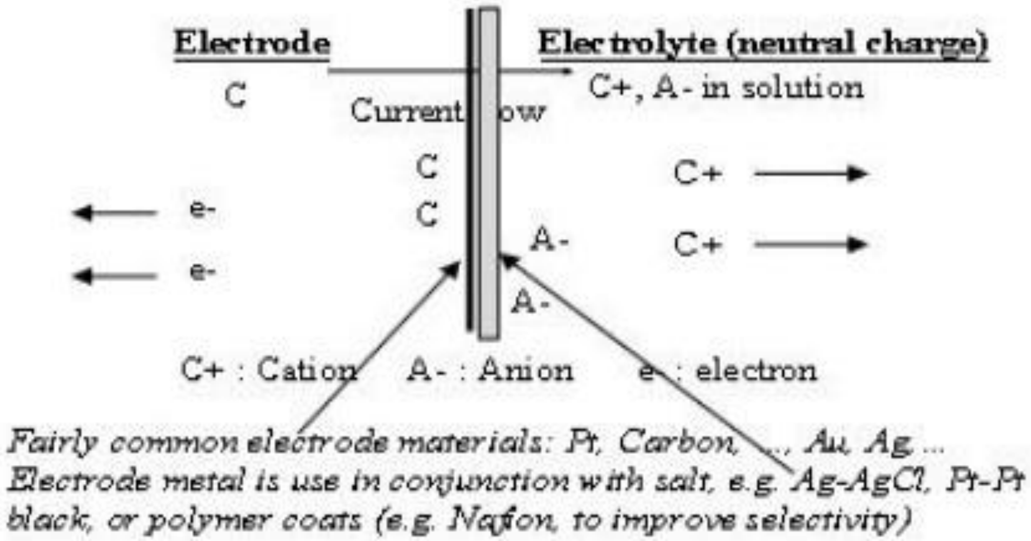


Figure 1.5 Electrolyte Interface

HALF CELL POTENTIAL or ELECTRODE POTENTIAL

- *A characteristic potential difference established by the electrode and its surrounding electrolyte which depends on the metal, concentration of ions in solution and temperature.*
- *Voltage developed at an electrode – electrolyte interface*
- *Half cell potential cannot be measured without a second electrode.*
- *The half cell potential of the standard hydrogen electrode has been arbitrarily set to zero. Other half cell potentials are expressed as a potential difference with this electrode.*

Bio Potential Electrodes

- *Reason for Half Cell Potential : Charge Separation at Interface*

- *Oxidation or reduction reactions at the electrode-electrolyte interface lead to a double-charge layer, similar t o that which exists along electrically active biological cell membranes.*

- ***Polarization -****If there is a current between the electrode and electrolyte, the observed half cell potential is often altered due to polarization.*

Measuring Half Cell Potential

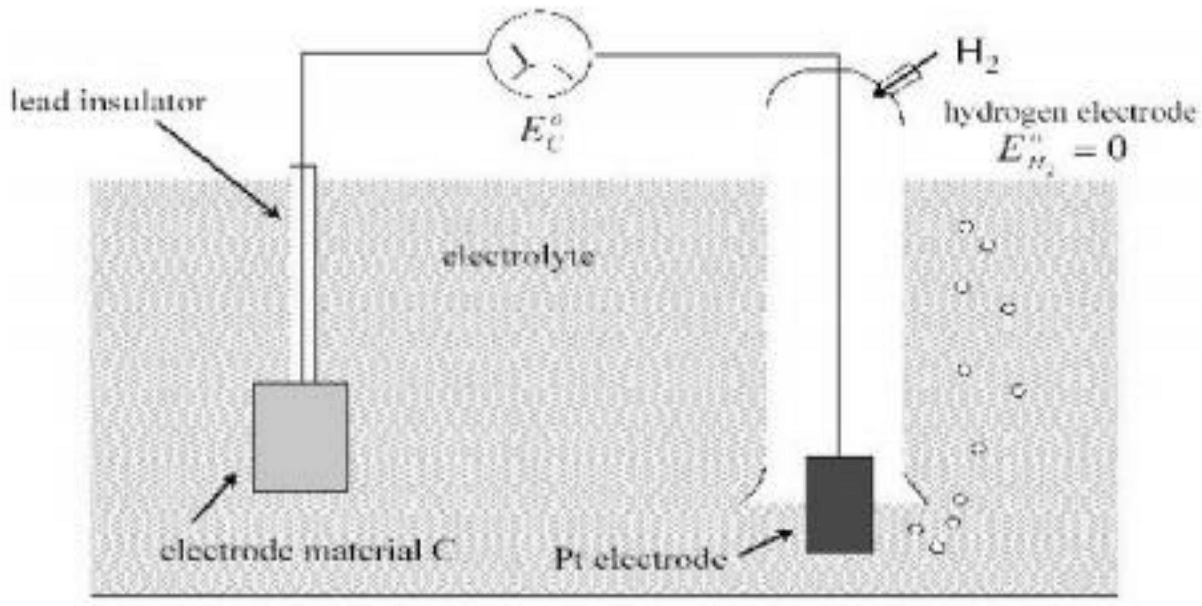


Figure 1.6 Half Cell Potential

Nernst Equation

- *When two aqueous ionic solutions of different concentration are separated by an ion-selective semi-permeable membrane, an electric potential exists across the membrane.*

- *The Nernst equation for half cell potential is*

$$E=E^{0} + R\ T/n[a_c^{\gamma} a_d / a_A^{\alpha} a_B^{\beta}]$$

where

- *E^0 : Standard Half Cell Potential*
- *E : Half Cell Potential*
- *a : Ionic Activity (generally same as concentration)*
- *n : Number of valence electrons involved*

Polarizable and Non-Polarizable Electrodes

- *Perfectly Polarizable Electrodes*: *These are electrodes in which no actual charge crosses the electrode-electrolyte interface when a current is applied. The current across the interface is a displacement current and the electrode behaves like a capacitor. Example : Ag/AgCl Electrode*

- *Perfectly Non-Polarizable Electrode*: *These are electrodes where current passes freely across the electrode-electrolyte interface, requiring no energy to make the transition.*

- *Example: Ag-AgCl is used in recording while Pt is use in stimulation*

Polarizable and Non-Polarizable Electrodes

- C_d : capacitance of electrode-eletrolyte interface
- R_d : resistance of electrode-eletrolyte interface
- R_s : resistance of electrode lead wire
- E_{cell} : cell potential for electrode

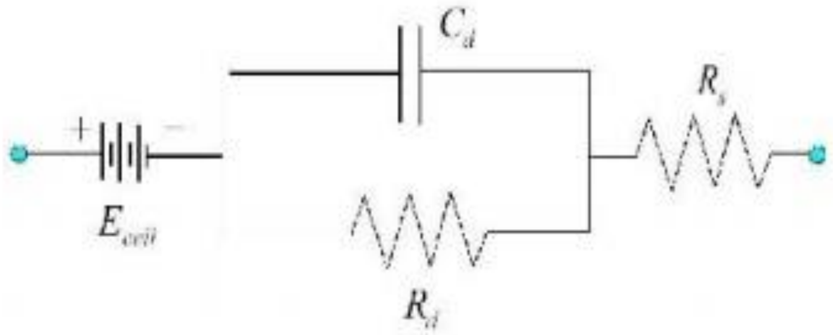


Figure 1.7 Equivalent Circuit

Motion Artifact

- *When the electrode moves with respect to the electrolyte, the distribution of the double layer of charge on polarizable electrode interface changes. This changes the half cell potential temporarily.*

- *If a pair of electrodes is in an electrolyte and one moves with respect to the other, a potential difference appears across the electrodes known as the **motion artifact.** This is a source of noise and interference in biopotential measurements.Motion artifact is minimal for non-polarizable electrodes*

Body Surface Recording Electrodes

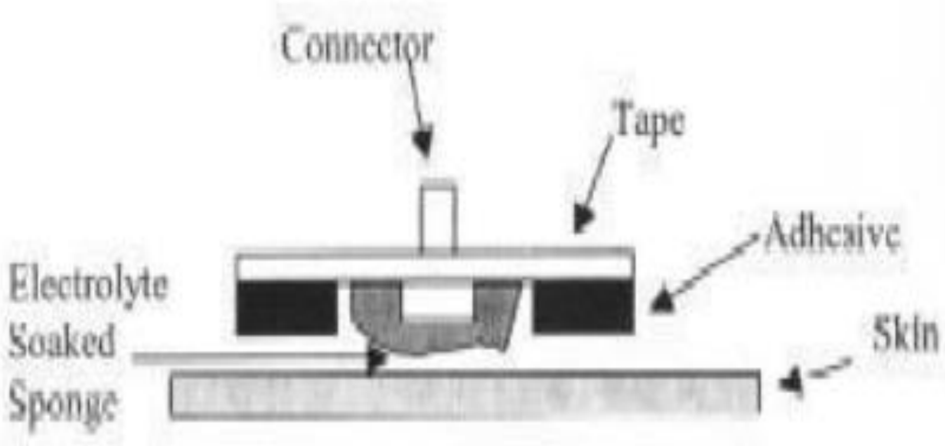


Figure 1.8 Body surface Recording Electrodes

Commonly Used Biopotential Electrodes

- *Metal Plate Electrodes are*

- *Suction Electrodes*
- *Floating Electrodes*
- *Flexible Electrodes*

PURPOSE OF ELECTRODE PASTE

- *Dry outer skin – highly non-conductive*
- *- No good electrical contact with an electrode*
- *- should be washed thoroughly*
- *- to be rubbed briskly to remove some of the outer cells*
- *- to be coated with an electrically conductive paste – electrode paste*

PURPOSE OF ELECTRODE PASTE

- *Electrode is applied to the prepared site*
- *Held in place with a rubber strap or a length of tape*
- *Electrode paste decreases the impedance of the contact*
- *Reduces the artifacts resulting from movement of the electrode or patient*

PURPOSE OF ELECTRODE PASTE

- *Conductivity of the skin is directly proportional to moisture of the skin*
- *For example, ECG electrode contact impedance on dry skin is about 100 kiloohms*
- *Equivalent capacitance component is about 0.01 microfarad*
- *After the application of the electrode paste, contact impedance is reduced to 10 kiloohms and the capacitance is increased to 0.1 microfarad*

PURPOSE OF ELECTRODE PASTE

- *Electrode contact impedance varies with fat content, blood supply and electrode contact pressure*
- *Even after the application of electrode paste, the contact impedance decreases with increase of frequency of the signal*
- *Among alcohol, electrode paste (electrolyte), saline solution and multipoint electrode,*
- *Multipoint electrode has less contact impedance about 4 kiloohms and alcohol has greater impedance*

ELECTRODE MATERIAL

- *Electrode, electrode paste and body fluids can produce battery like action causing ions to accumulate on the electrodes*
- *Such polarisation of the electrode can adversely affect the signal transfer*
- *To minimise this polarisation, the electrode should be made of a material relatively inert to body chemicals*
- *Polarisation effect can be reduced by coating the electrodes with some electrolytes*

ELECTRODE MATERIAL

- *By electrolytically coating a piece of pure silver with silver chloride, the silver-silver chloride electrolyte is developed*
- *Half cell potential is 2.5 millivolts*
- *It reduces the noise voltage and increases the stability electrochemically*
- *It stabilizes the half cell potential and no movement artifacts*

ELECTRODE MATERIAL

- *It also reduces the low frequency electrode – electrolyte impedance*
- *Silver – silver chloride electrodes are extensively used in bioelectric instrumentation*
- *Types : three types of electrodes*
- *microelectrodes*
- *depth and needle electrodes*
- *surface electrodes*

TYPES OF ELECTRODES

- *MICROELECTRODES – used to measure the bioelectric potential near or within a single cell – also known as intracellular electrodes*
- *DEPTH AND NEEDLE ELECTRODES – used to measure the bioelectric potentials of the highly localized extracellular regions in brain or bioelectric potentials from a specific group of muscles*
- *SURFACE ELECTRODES – used to measure the potentials available from the surface of the skin and are used to sense the potentials from heart, brain and nerves*

MICROELECTRODES

- *Divided into metallic and nonmetallic*
- *Nonmetallic microelectrode – micropipet*
- *Should have a smaller diameter*
- *There should not be any damage to the cells, during insertion of the electrode into the cell*
- *It is located within the cell while the reference electrode is situated outside the cell*
- *Size of the electrode is determined by the size of the cell*
- *Size of the cell – 50 microns; diameter of the tip – 0.5 to 5 microns*

METAL MICROELECTRODE

- *Formed by electrolytically etching the tip of a fine tungsten or stainless steel wire to a fine point – electropointing*
- *Coated almost to the micro tip with an insulating material*
- *To reduce the impedance, some electrolytic processing like chloriding the tip and then developing by the photographic developer can be performed*

METAL MICROELECTRODE

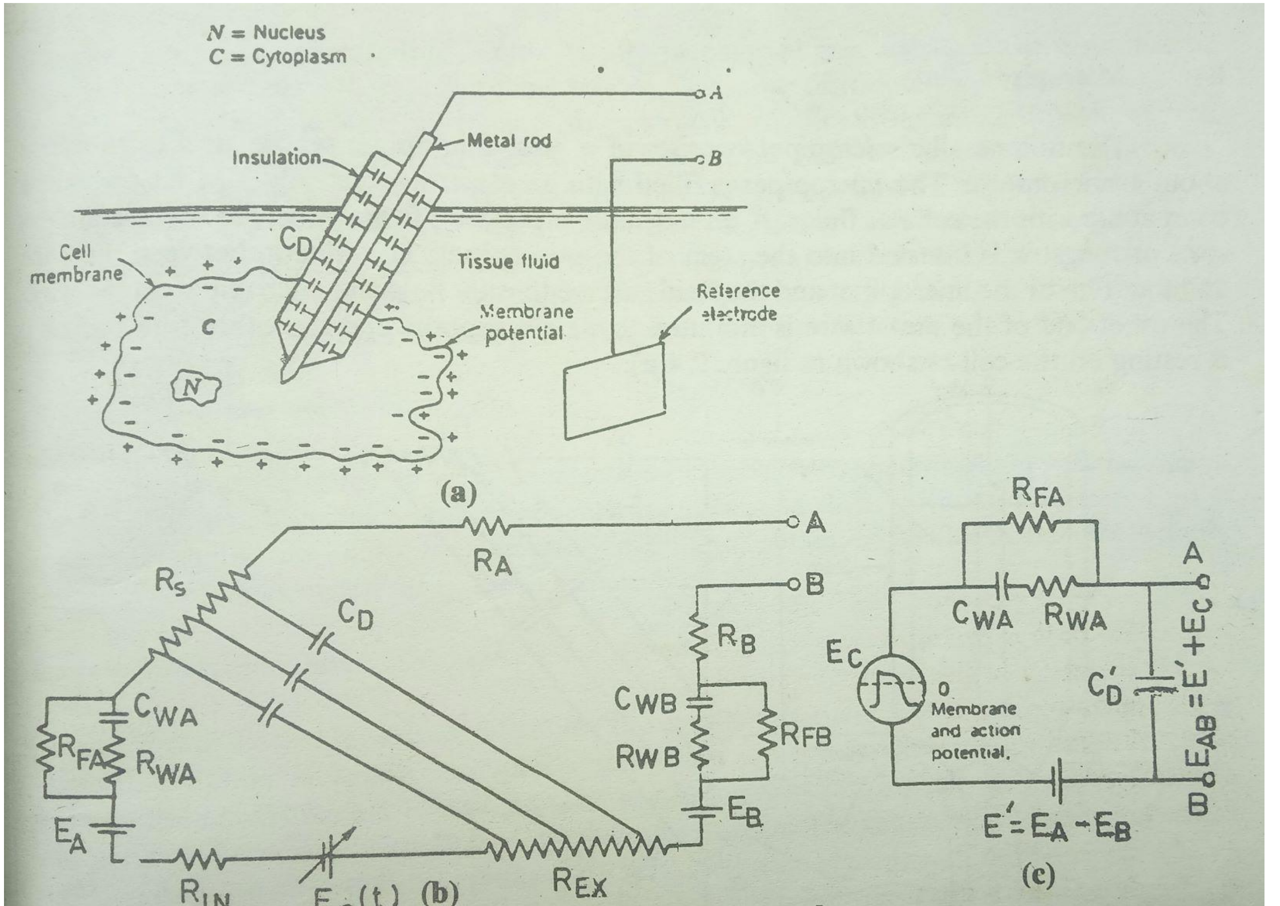


Fig.2.3. Metal Microelectrode

METAL MICROELECTRODE

- *a – position of the electrodes*
- *b – electrical equivalent*
- *Voltage measured is the difference between the instantaneous potential of the microelectrode and the reference electrode*
- *It is the sum of the three potentials*
- E_A *– metal electrode – electrolyte potential at the microelectrode tip*
- E_B *– reference electrode – electrolyte potential*
- E_C *– variable cell membrane potential*

METAL MICROELECTRODE

- *R_A – resistance of the connecting wire – negligible*
- *R_S – resistance of the shaft of the microelectrode – negligible*
- *R_{FA}, R_{WA}, C_{WA} – impedance of the microelectrode tip – intracellular fluid interface*
- *R_{IN} - resistance of the intracellular fluid*
- *R_B – resistance of the wire connected to the reference electrode – negligible*
- *R_{FB}, R_{WB}, C_{WB} – impedance of the reference electrode– extracellular fluid interface*

METAL MICROELECTRODE

- *R_{EX} - resistance of the extracellular fluid*
- *C_D – distributed capacitance between the insulated shaft of the microelectrode and the extracellular fluid*
- *Capacitance between the tip of the microelectrode and the intracellular fluid is negligible as the potential difference across it does not change*

METAL MICROELECTRODE

- *Area of the reference electrode is many times greater than the metal electrode's tip, whose cross section is very small, its impedance is negligible*
- *The impedance of the microelectrode tip is inversely proportional to the area of the tip and frequency*
- *When the electrode output s coupled with an amplifier, the low frequency components of the bioelectric potential will be attenuated if the input impedance of the amplifier is not high*
- *When the input impedance of the amplifier is not high enough, it behaves as a high pass filter*

METAL MICROELECTRODE