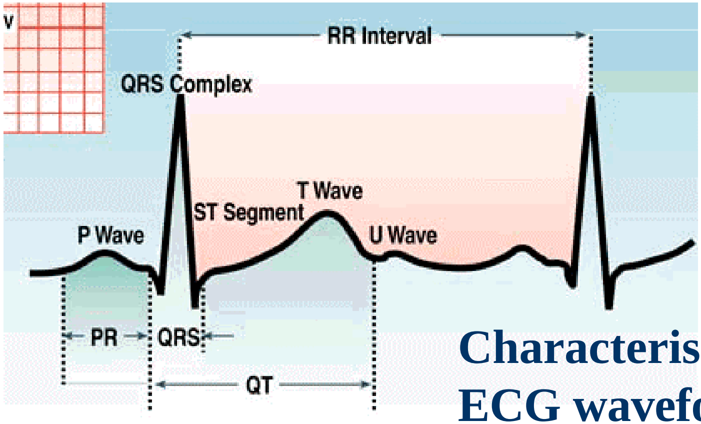
Biopotential electrodes

– Bioelectric signals
– Biopotential electrode models
– Electrode types

Biomedical Electronics and Instrumentation
Department of Electronic Engineering

Bioelectric activity

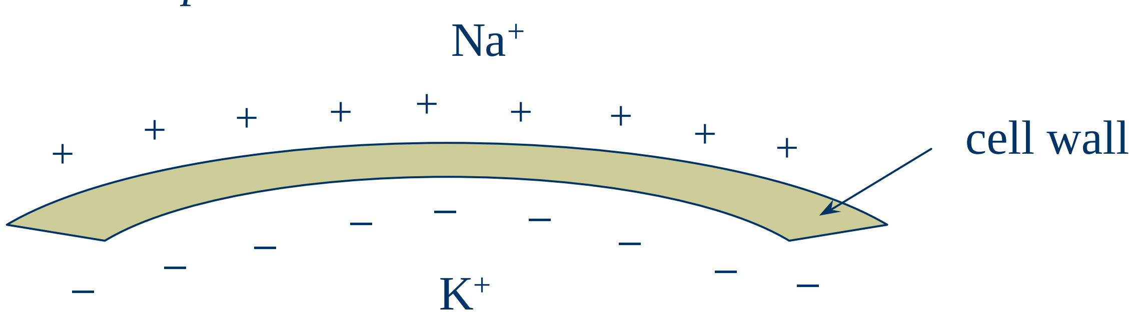
- Electrical signals produced by various bodily activities are used in monitoring / diagnosis
  - Measured signals are generally compared with normal reference signals
  - Variations in signals can provide accurate diagnosis
- Examples include
  - Electrocardiography (ECG) – activity of different sections of the heart
  - Electroencephalography (EEG) – electrical activity of the brain
  - Electromyography (EMG) – electrical activity of the muscles
- Signals are characterised by
  - Amplitude
  - Frequency / time duration
  - Waveshape



Characteristics of ECG waveforms

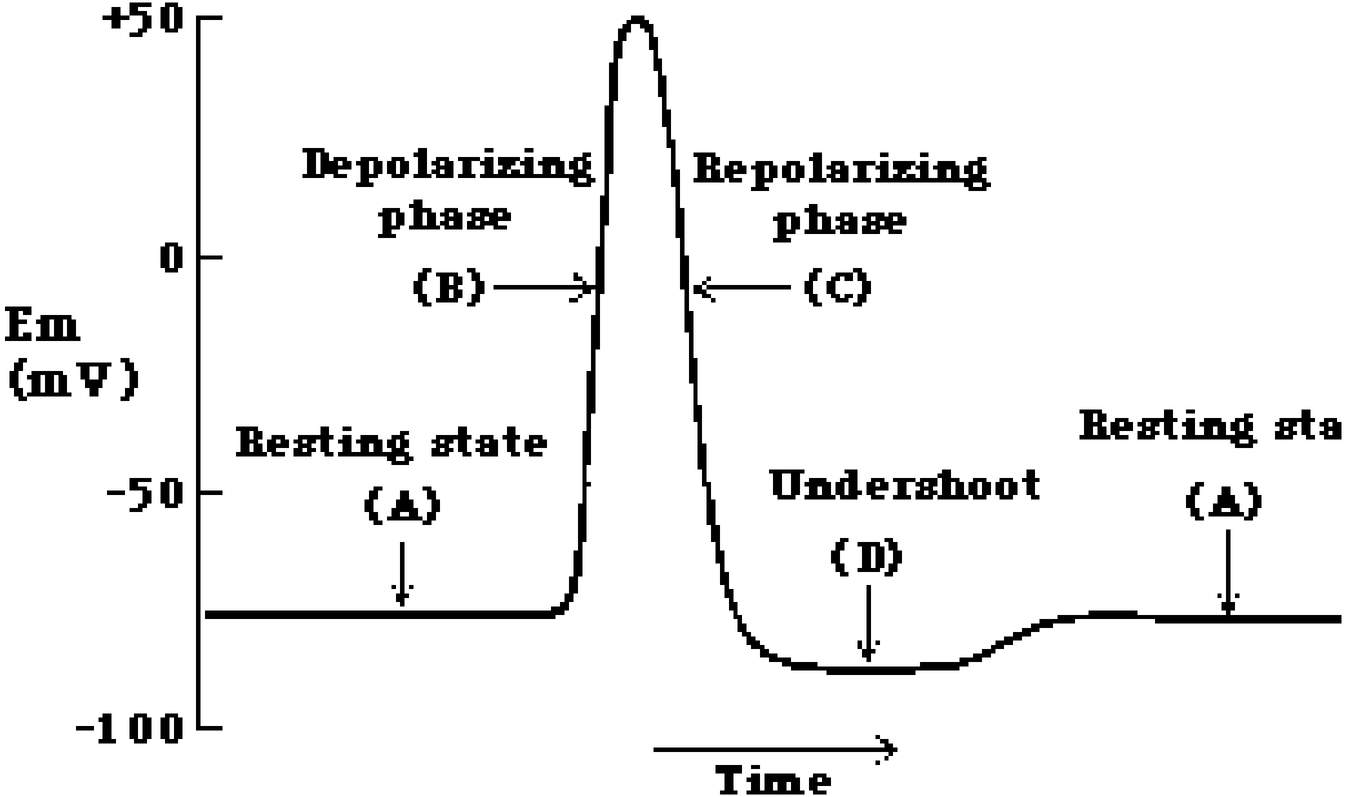
Biopotential signals

- Electrical activity is explained by differences in ion concentrations within the body (sodium, Na^+; cloride, Cl^-; potassium, K^+)
  - A potential difference (voltage) occurs between 2 points with different ionic concentrations
  - Cell membranes at rest are more permeable to some ions (e.g. K^+, Cl^-) than others (e.g. Na^+)
    - Na^+ ions are pumped out of the cells, while K^+ ions are pumped in
    - Due to a difference in rates of pumping ($Na^+ > K^+$) , a difference in +'ive ion concentration results
    - A –'ive electrical potential is established between the inside and outside of the cell; this is estimated to be approx. –70 mV.
    - Cell is said to be *polarised*



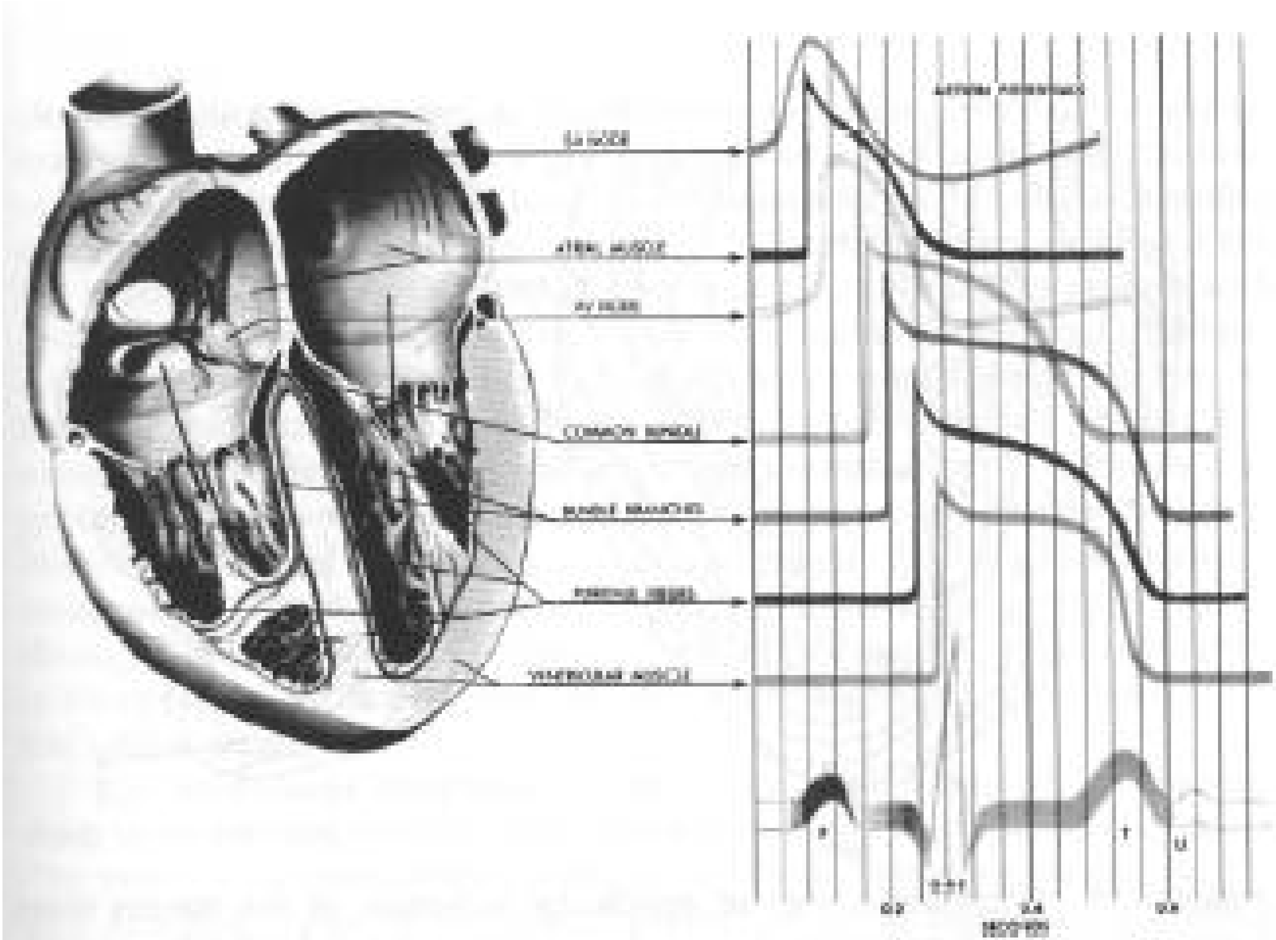
- Action potential
  - When a cell is electrically stimulated (through the central nervous system), the permeability of the cell membrane changes
    - Na^+ ions rush into the cell, and K^+ ions rush out
    - Again, due to a difference in rates of flow, the ion concentration changes (more +'ive ions inside cell than outside)
    - Cellular potential becomes +'ive : 20 – 40 mV. This lasts for a few milliseconds
    - Cell is said to be *depolarised*
  - After the stimulus, the permeability of the cell membrane returns to its original value, and the rest potential is restored
    - Due to unequal pumping rates of Na^+ and K^+ ions
    - Time taken for restoration is called the refractory period
    - Cell is said to be *repolarised* during this time
  - The resulting variation in cellular potential with time is known as the action potential

Typical action potential signal



- ECG, EEG etc signals are the resultant of several action potentials produced by a combination of different cells

Action potentials → measured waveforms



- Propagation of action potential through different body tissues produces final waveform recorded by electrodes

Biopotential sensors / electrodes

- Biopotential electrodes transduce *ionic* conduction to *electronic* conduction so that biopotential signals can be viewed and/or stored
- They generally consist of metal contacts packaged so that they can be easily attached to the skin or other body tissues

Metal plate electrodes

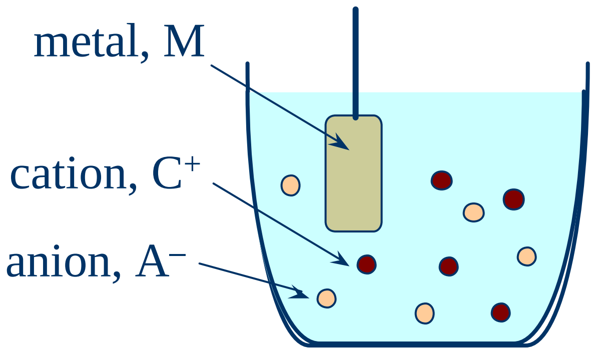
Suction electrode

Needle electrodes

  - Different types include surface macroelectrodes, indwelling macroelectrodes & microelectrodes
  - Skin and other body tissues act as electrolytic solutions

Half-cell potential

- The performance of an electrode may be described in terms of a metal – electrolyte interface



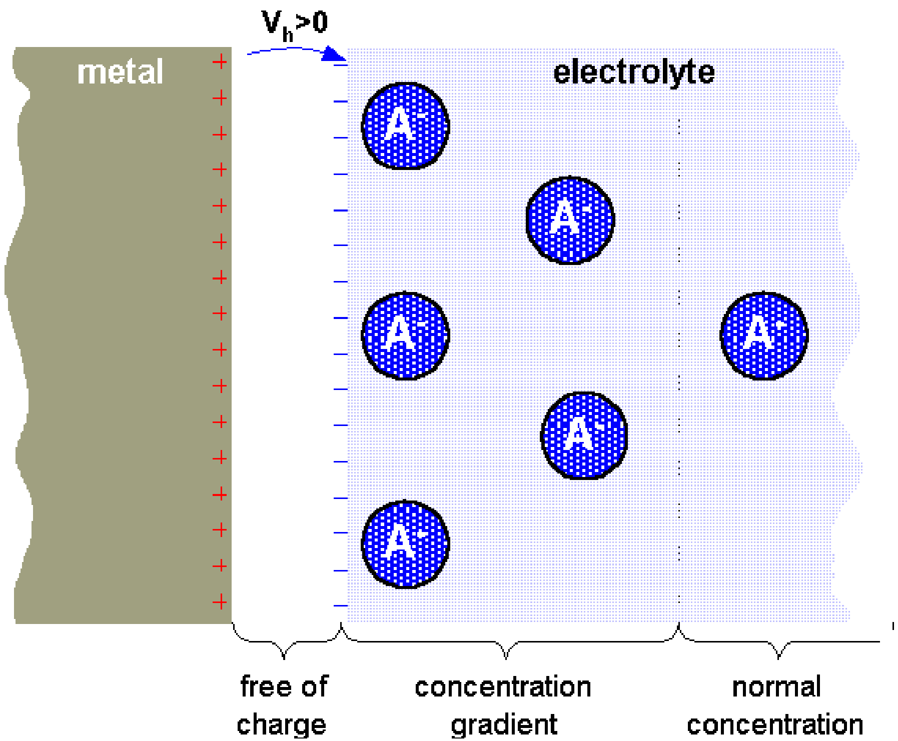
$$M \rightarrow M^{+} + e^{-}$$

$$C^{+} + e^{-} \rightarrow C$$

- Electrode discharges some metallic ions into electrolytic solution
  - Increase in # free electrons in electrode and in # +ive cations in solution
- OR ions in solution combine with metallic electrodes
  - Decrease in # free electrons in electrode and in # +ive cations in solution
- As a result, a charge gradient builds up between the electode and electrolyte and this in turn creates a potential difference; i.e. the electrode potential or half-cell potential, V_h.

Electrode double layer

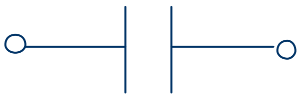
- For both mechanisms, two parallel layers of opositely charged ions are produced; i.e. the electrode double layer :
  - E.g. when metal ions recombine with the electrode :



  - The excess of negative anions is replaced with positive cations in the case of metal ions discharging into solution, and V_h is then < 0.

Polarisation

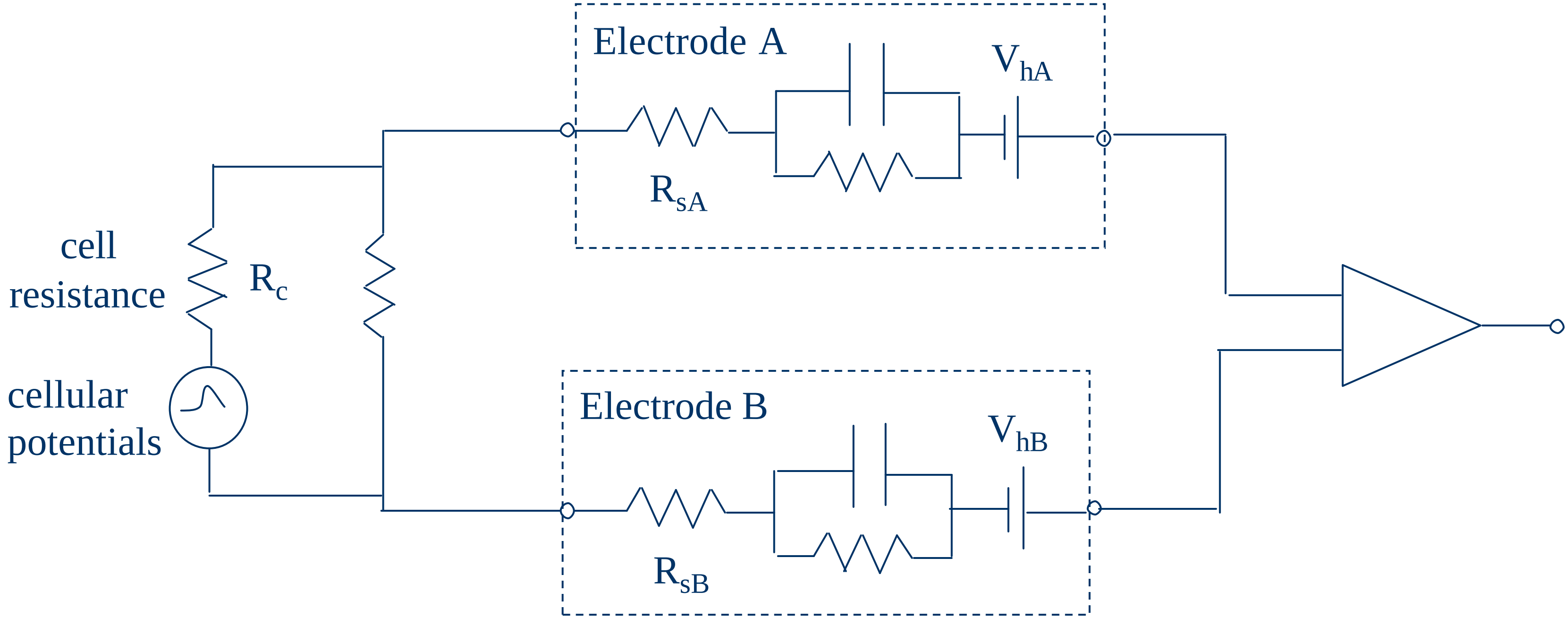
- A perfectly polarised electrode is one in which there is no net tranfer of charge across the metal / electrolyte interface.
  - Either metal ions are discharged OR electrolytic ions recombine
  - Only displacement current flows
  - Interface impedance is represented as a capacitor



- A perfectly non-polarised electrode is one in which there is no impedance to charge transfer between the metal and electrolyte
  - Both mechanisms of charge transfer occur
  - There is no double layer build up
  - Interface impedance is represented as a resistor

- In practice, both mechanisms occur to some extent and interface impedance therefore has components of resistance *and* capacitanc

Electrode circuit model



- Biopotential is measured as the difference in readings between two electrodes
  - Ideally, the half-cell potential is cancelled out
- Model assists in amplifier design (later)
  - Source resistance vs. amplifier input impedance
  - Frequency dependance

Typical electrode materials

reduction reaction	$E^o \ (V)$
$Al^{3+} + 3e^- \rightarrow Al$	-1.662
$Zn^{2+} + 2e^- \rightarrow Zn$	-0.762
$Cr^{3+} + 3e^- \rightarrow Cr$	-0.744
$Fe^{2+} + 2e^- \rightarrow Fe$	-0.447
$Cd^{2+} + 2e^- \rightarrow Cd$	-0.403
$Ni^{2+} + 2e^- \rightarrow Ni$	-0.257
$Pb^{2+} + 2e^- \rightarrow Pb$	-0.126
$2H^+ + 2e^- \rightarrow H_2$	0.000
$AgCl + e^- \rightarrow Ag + Cl^-$	$+0.222$
$Hg_2Cl_2 + 2e^- \rightarrow 2Hg + 2Cl^-$	$+0.268$
$Cu^{2+} + 2e^- \rightarrow Cu$	$+0.342$
$Cu^+ + e^- \rightarrow Cu$	$+0.521$
$Ag^+ + e^- \rightarrow Ag$	$+0.780$
$Au^{3+} + 3e^- \rightarrow Au$	$+1.498$
$Au^+ + e^- \rightarrow Au$	$+1.692$

Standard Hydrogen electrode

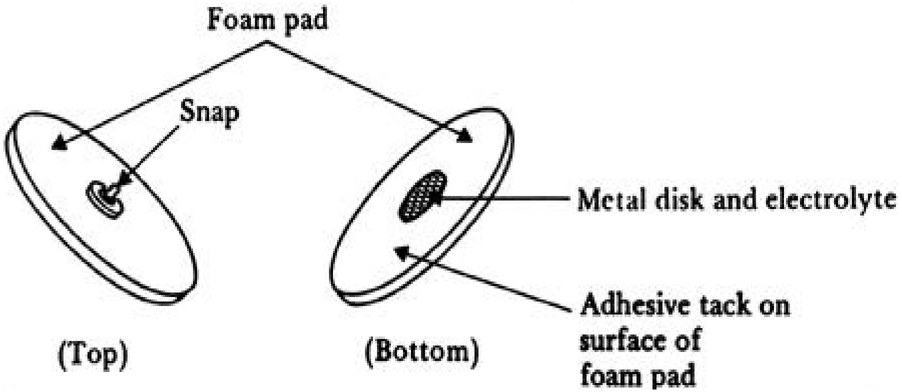
Note: Ag-AgCl has low junction potential & it is also very stable -> hence used in ECG electrodes!

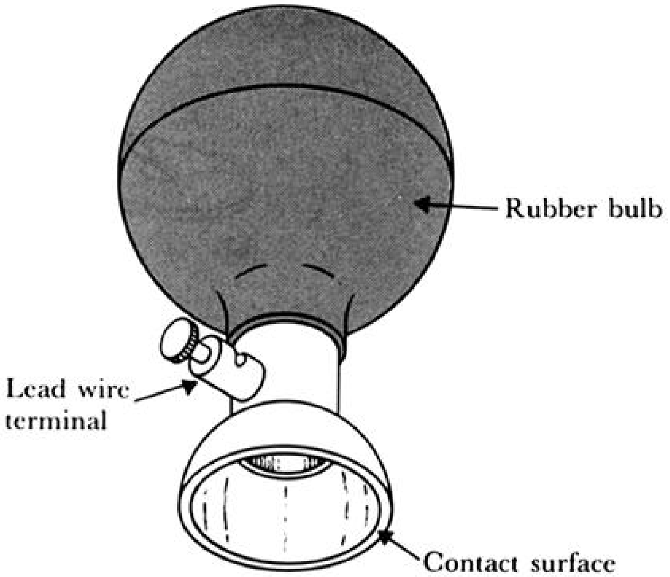
Problem of half-cell potential

- Typical half-cell potential values (at DC) are much larger than AC measurement signals
  - V_e : 0.1 – 0.5 V vs. V_{ECG} : 1 – 2 mV & V_{EEG} : ~ 50 µV
  - Even if identical electrodes are used and a differential signal is measured, there will be differences in V_e values due to variation in placement positions
- Solutions include :
  - Use of a differential DC amplifier – however, small remaining differences will be amplified by the same level as low level signals to be detected.
  - Include a DC offset circuit to subtract the half-cell potential – this approach is limited by the time-varying nature of the offset due to motion between the skin and electrode.
  - Include a high pass filter to remove the DC offset – this provides the best results for measurement signals with frequency much higher than that of offset variations

Surface electrodes

- These are placed in contact with the skin of the subject

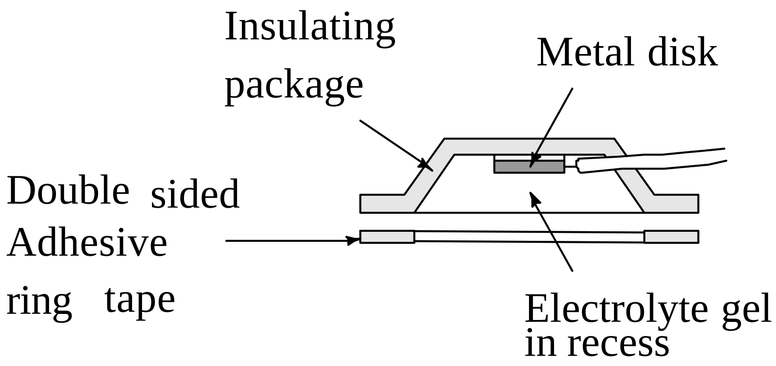




- Problem of motion artifact
  - Electrode movement produces unwanted signals due to change in electrode – electrolyte interface

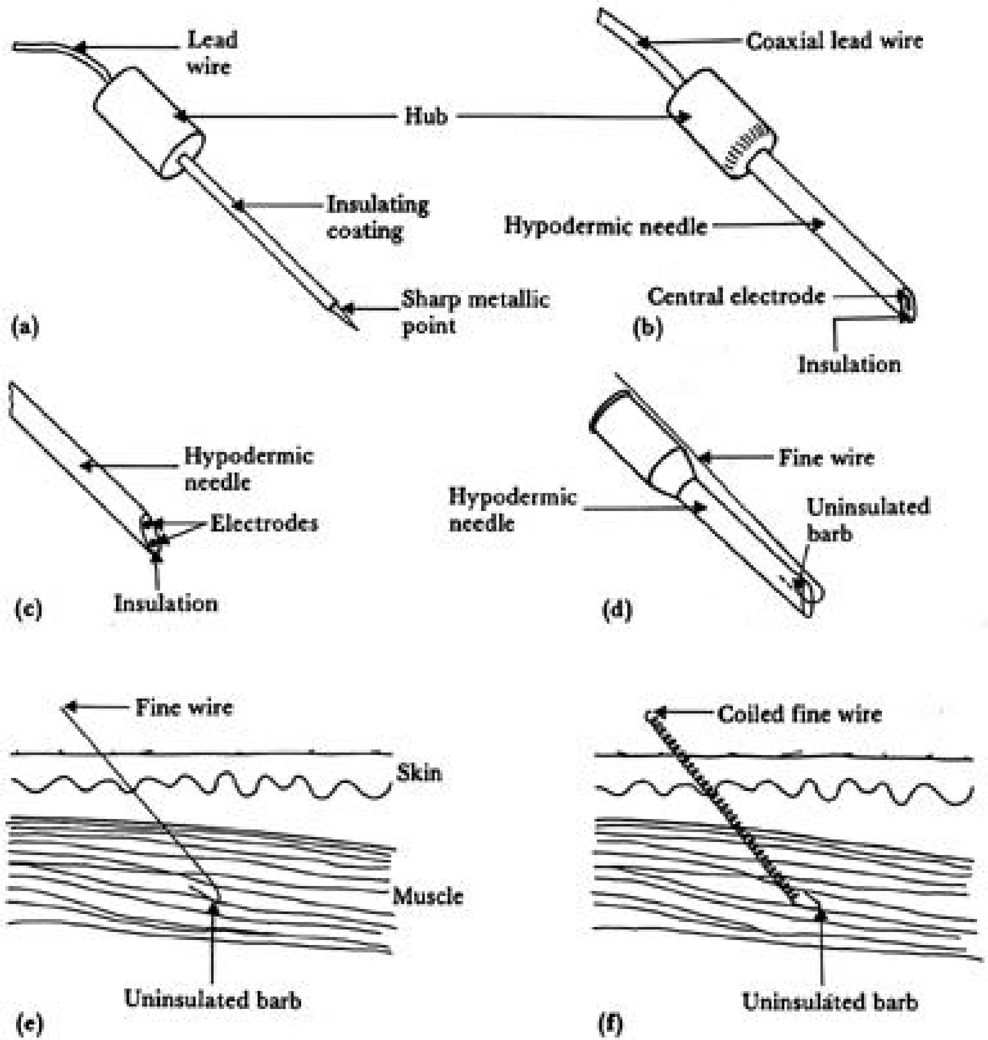
Floating electrodes

- Conductive paste reduces effect of electrode slippage and resulting motion artifact :



Needle electrodes

- Mostly used for contacting with internal body tissues :



(a) Insulated needle electrode .

(b) Coaxial needle electrode .

(c) Bipolar coaxial electrode .

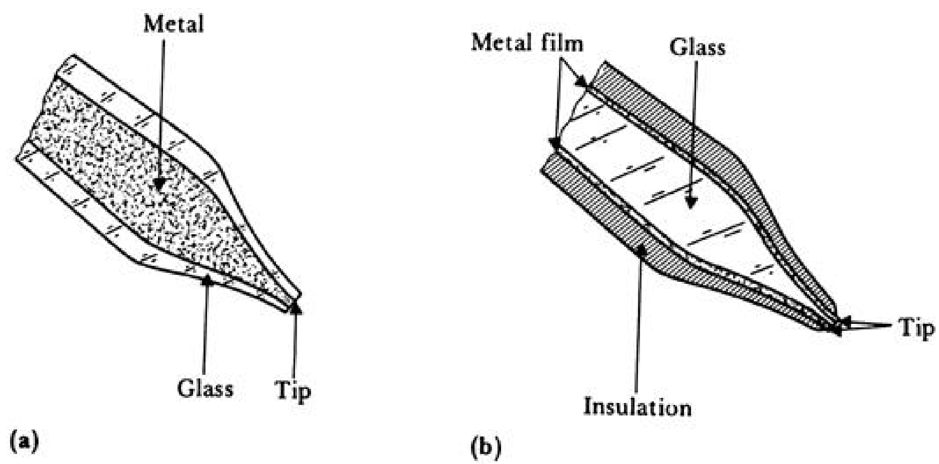
(d) Fine -wire electrode connected to hypodermic needle, before being inserted .

(e) Cross -sectional view of skin and muscle, showing coiled fine -wire electrode in place .

Microelectrodes

- Used to measure biopotential signals at the cellular level :

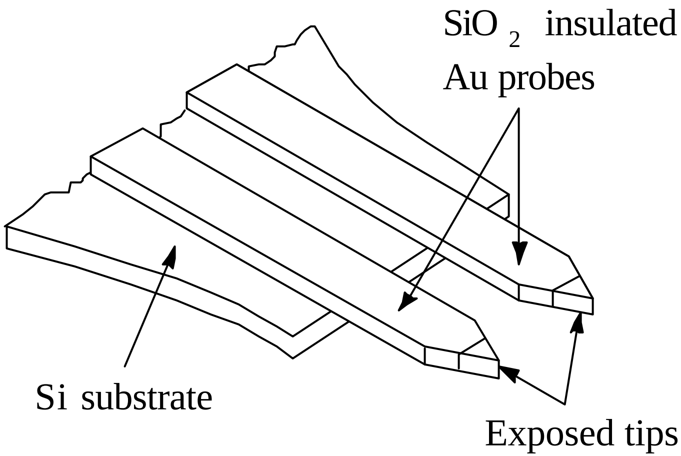
Metal Supported Microelectrodes



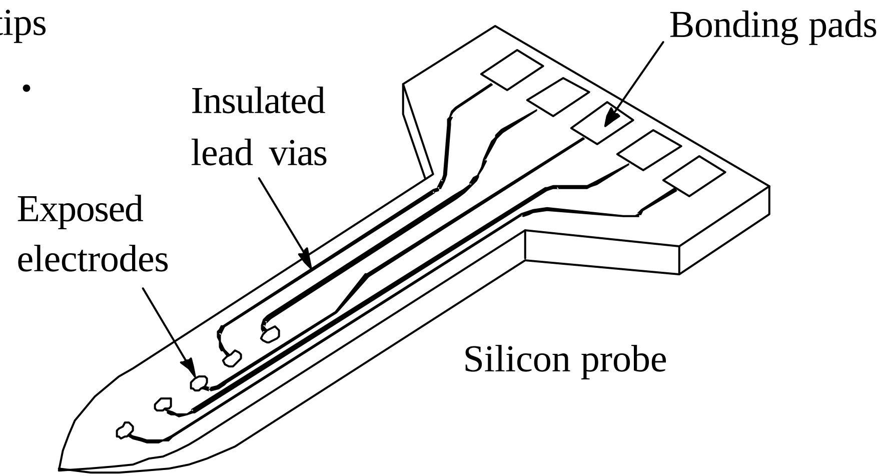
(a) Metal inside glass (b) Glass inside metal

- Due to small dimensions (µm), impedance levels are high
  - Amplifier needs very high input impedance

Microtechnology / MEMS



(a) Beam -lead multiple electrode



(b) Multielectrode silicon probe