18BEBME403 BIOSENSORS AND TRANSDUCERS 3 0 0 3 100

OBJECTIVES

- To provide the knowledge of basic concepts such as generalized instrumentation system, general properties of input transducers, static and dynamic characteristics of transducers and sensors.
- To provide a thorough understanding of principle and working of transducers and sensors used for displacement, motion, pressure and temperature measurement, biopotential electrodes, chemical sensors, biosensors, fiber optic sensors, and radiation sensors.
- To study the biomedical applications of the above transducers and sensors.
- To perform experiments based on some of the above transducers and sensors.

INTENDED OUTCOMES

After completion of the above course the students shall be competent in the following ways:

- They have a clear understanding of generalized medical instrumentation system, general properties of input transducers, static and dynamic characteristics of transducers and sensors.
- They have a thorough understanding of various transducers and sensors taught in the course.
- They are able to apply the transducers and sensors learnt in the course in suitable medical contexts.
- They have a working knowledge of some of the transducers and sensors that they have learnt in the course.

UNIT I INTRODUCTION TO TRANSDUCERS AND ITS CHARACTERISTICS (10)

Introduction: Generalized Instrumentation System, General Properties of Input Transducer Static Characteristics: Accuracy, Precision, Resolution, Reproducibility, Sensitivity, Drift, Hysteresis, Linearity, Input Impedance and Output Impedance. Dynamic Characteristics: First Order and Second Order Characteristics, Time Delay, Error Free Instrument, Transfer Functions. Design Criteria, Generalized Instrument Specifications.

UNIT II MEASUREMENTS (8)

Displacement, motion and Pressure Measurement: (with applications) Resistive: Potentiometers, Strain Gauges and Bridge Circuits. Inductive: Variable Inductance and LVDT Capacitive type, Piezoelectric Transducers. Types of Diaphragms, Bellows, Bourdon Tubes.

UNIT III THERMAL MEASUREMENTS (6)

Temperature Measurement: Thermistor, Thermocouple, Resistive Temperature Detector, IC based Temperature Measurement, Radiation Sensors and Applications .

UNIT IV **ELECTRODES**
(10)

Biopotential Electrodes: Electrodes Electrolyte Interface, Half-Cell Potential, Polarization, Polarizable and Non Polarizable, Electrodes, Calomel Electrode, Electrode Circuit Model, Electrode Skin-Interface and Motion Artifact. Body Surface Electrodes. Internal Electrodes: Needle and Wire Electrodes (Different Types). Microelectrodes: Metal, Supported Metal Micropipette (Metal Filled Glass And Glass Micropipette Electrodes)

UNIT V **BIOSENSORS**
(11)

Chemical Sensors: Blood gas and Acid- Base Physiology Potentiometric Sensors, Ion Selective Electrodes, ISFETS. Amperometric Sensors, Clark Electrode with examples - pH, pO2, pCO2 Electrodes, Transcutaneous Arterial Oxygen Tension, Carbon Dioxide measurements: capnostat. Fiber Optic Sensors: Design Principles in Fabrication of Fiber Optic Sensors - Temperature, Chemical, Pressure. Biosensor: Classifications: Biological phenomenon, Transduction Phenomenon i.e. Enzyme Sensor and Electrode based: Affinity Sensors (Catalytic Biosensors), Two examples of each Biosensors and Immunosensors.

Total : 45

TEXT BOOKS:

S.NO.	Author(s) Name	Title of the book	Publisher	Year of publication
1	Richard S.C. Cobbold	Transducers for Biomedical Measurements: Principles and Applications	John Wiley & Sons	1974
2	Hermann K P. Neubert	Instrument Transducer – An Intro to their performance and	Hermann K P. Neubert	2000
3	Harry N, Norton.	Biomedical sensors – fundamentals and application	Harry N, Norton.	2001
4	Tatsuo Togawa, Toshiyo Tamma and P. Ake Öberg	Biomedical Transducers and Instruments	Tatsuo Togawa,	1994
5	Nandini K	Electronics in Medicine and Biomedical Instrumentation	Jog PHI Second Edition	2013

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1	La Geddes and L.E. Baker	Principles of applied Biomedical Instrumentation	La Geddes and L.E. Baker	1997
2	Leslie Cromwell, Fred. J. Weibell and Pfeiffer	Biomedical instrumentation and measurement	Leslie Cromwell, Fred. J. Weibell and Pfeiffer	2002
3	Richard Aston	Principles of Biomedical Instrumentation and Measurement	Merril Publishing Co., Columbus	1990
4	Ernest O. Doeblin	Measurement Systems, Application and Design	McGraw-Hill	1985
5	Jacob Fraden	Handbook of Modern Sensors – Physics, Design and Application	AIP press	2000

KARPAGAM ACADEMY OF HIGHER EDUCATION
COIMBATORE-21
Faculty of Engineering
Department of Biomedical Engineering

LECTURE PLAN

Name of the staff : **Mr.T.S.Belliraj**
Designation : **Assistant Professor.**
Class : **II-B.E BME**
Subject : **BIOSENSORS AND TRANSDUCERS**
Subject code : **18BEBME403**

Sl.No.	Topics to be covered	Time Duration
	UNIT I INTRODUCTION TO TRANSDUCERS AND ITS CHARACTERISTICS	
1	Introduction	01
2	Generalized Instrumentation System	01
3	General Properties of Input Transducer Static Characteristics: Accuracy, Precision, Resolution	01
4	Sensitivity, Drift, Hysteresis, Linearity, Input Impedance and Output Impedance	01
5	Dynamic Characteristics: First Order and Second Order Characteristics	02
6	Time Delay, Error Free Instrument	01
7	Transfer Functions. Design Criteria	01
8	Generalized Instrument Specifications	01
	UNIT II MEASUREMENTS	
9	Displacement, motion	01
10	Pressure Measurement: (with applications)	01
11	Resistive: Potentiometers	01
12	Strain Gauges and Bridge Circuits	01
13	Inductive: Variable Inductance	01
14	LVDT Capacitive type	01
15	Piezoelectric Transducers	01
16	Types of Diaphragms	
17	Bellows, Bourdon Tubes	01
	UNIT III THERMAL MEASUREMENTS	
18	Temperature Measurement: Thermistor	02
19	Thermocouple, Resistive Temperature Detector	02
20	IC based Temperature Measurement	02
21	Radiation Sensors and Applications	02
	UNIT IV ELECTRODES	
22	Biopotential Electrodes: Electrodes Electrolyte Interface	01
23	Half-Cell Potential, Polarization	01
24	Polarizable and Non Polarizable, Electrodes	01
25	Calomel Electrode, Electrode Circuit Model	01
26	Electrode Skin-Interface and Motion Artifact.	01
27	Body Surface Electrodes. Internal Electrodes: Needle and Wire Electrodes (Different Types).	01
28	Microelectrodes: Metal	01

29	Supported Metal Micropipette (Metal Filled Glass And Glass Micropipette Electrodes)	01
	UNIT V BIOSENSORS	
30	Chemical Sensors: Blood gas and Acid- Base Physiology Potentiometric Sensors	01
31	Ion Selective Electrodes, ISFETS. Amperometric Sensors	01
32	Clark Electrode with examples - pH, pO2, pCO2 Electrodes	01
33	Transcutaneous Arterial Oxygen Tension	
34	Carbon Dioxide measurements: capnostat. Fiber	01
35	Optic Sensors: Design Principles in Fabrication of Fiber Optic Sensors	01
36	Temperature, Chemical, Pressure.	01
37	Biosensor: Classifications: Biological phenomenon	01
38	Transduction Phenomenon i.e. Enzyme Sensor	01
39	Electrode based: Affinity Sensors (Catalytic Biosensors)	01
40	Two examples of each Biosensors and Immunosensors.	01

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Staff In-Charge **HOD/ECE**

TRANSDUCERS

An Introduction

TRANSDUCERS

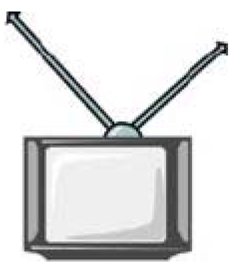
- A transducer is a device that converts energy from one form to another
- Energy forms can be mechanical, visual, aural, electrical, thermal, chemical, etc. (examples to follow)
- Used to change information into a form that can be easily transferred, stored, processed, interpreted, etc.

Types of Energy Transformations

- Electromagnetic - EM fields $\Longleftrightarrow$ current

Examples:

Receiving Antennas



Transmitting Antennas

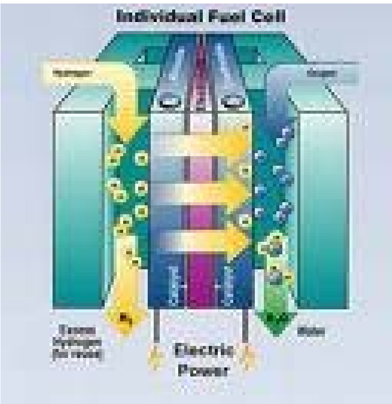
Types of Energy Transformations

- Electrochemical - substance → voltage

Examples:

pH Probe

Fuel Cell



Types of Energy Transformations

- Electromechanical - movement ↔ voltage

Examples:

Motor/Generator

Phonograph Cartridge

Types of Energy Transformations

- Electroacoustic - vibration ⟷ voltage

Examples:

Loudspeaker

Microphone

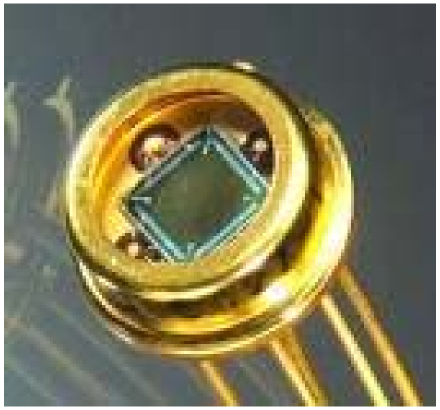
Types of Energy Transformations

- Photoelectric - light $\Leftrightarrow$ voltage

Examples:

Light Bulb

Photodiode



Types of Energy Transformations

- Thermoelectric - temperature ⟷ voltage

Examples:

Hotplate

Thermistor

Principles of Energy Transformation

Capacitive Transducers

Voltage between plates: $V_{ab} = Ed$

$$C = \frac{Q}{V} = \frac{Q}{Ed} = \frac{\varepsilon A}{d}$$

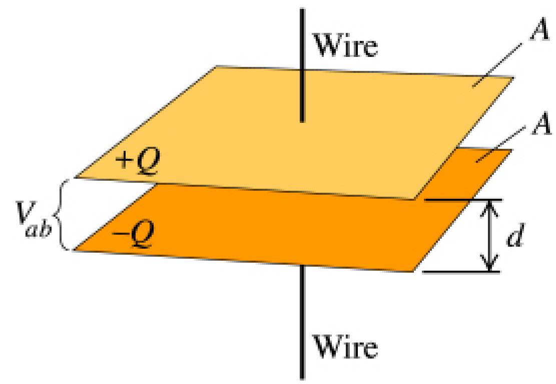
where:

Q = plate charge

ε = permittivity of dielectric

A = area of plates

d = distance between plates



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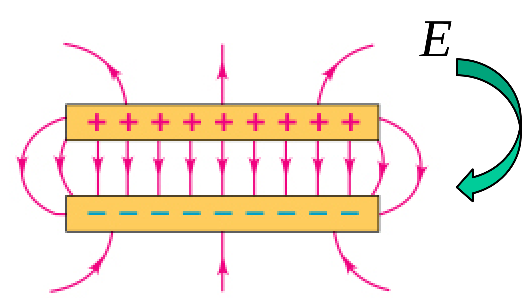

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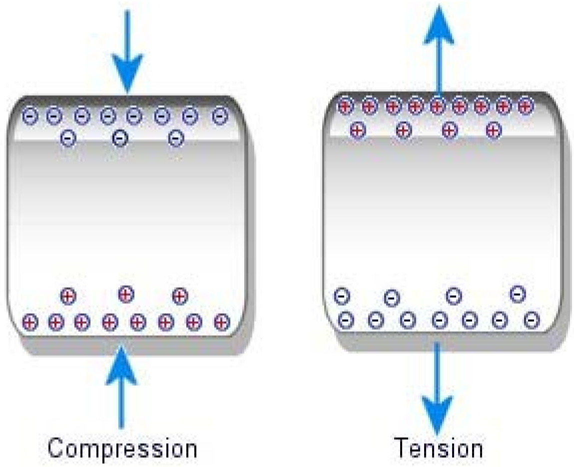
Principles of Energy Transformation

Piezoelectric Transducers

Voltage on opposite sides of piezoelectric crystal is dependent on magnitude and direction of force applied to the crystal.



Type of Piezoelectric Materials:

- •Natural crystals (quartz, rochelle salts)
- •Synthetic crystals (lithium phosphate)
- •Ferroelectric ceramics (barium titanate)

Principles of Energy Transformation

Electromechanical Transducers

- Some type of mechanical contact

- Convert physical change (movement, distance, etc.) to electrical signal (or *vice-versa*)

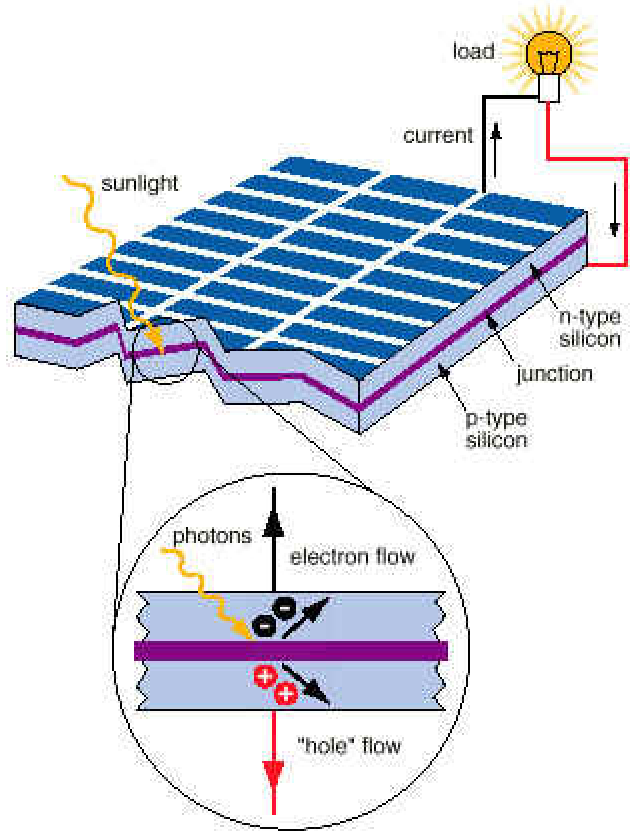
- Mouse - Movement of track ball causes electric signal

Principles of Energy Transformation

Photovoltaic Transducers

•Light of proper wavelength ionizes atoms in silicon base.

•Charges are recombined by flowing through load, creating electrical current.



Terminology

•Measurand - that property being quantified or transformed.

•Passive Transducer (Sensor) - one which draws its operating power from the measurand.

•Active Transducer - one which requires external power.

•Accuracy - how close is the measurement to the actual value?

•Resolution - how fine of a measurement can we make?

•Range - what input (and output) values are possible?

Terminology

- Sensitivity - how much does a change in input affect the output? (also called the scale factor.)

- Linearity - does the output change uniformly with the input?

- Repeatability - output signal should be the same whenever the measurand value is the same.

- Response Time - how quickly does the transducer respond to changes in the measurand value?

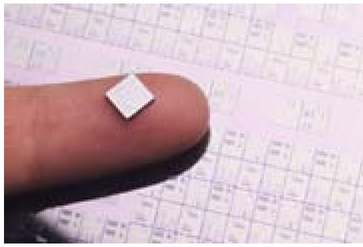
Packaging and Integration

Considerations:

- Technology
- Environment
- End User
- Cost

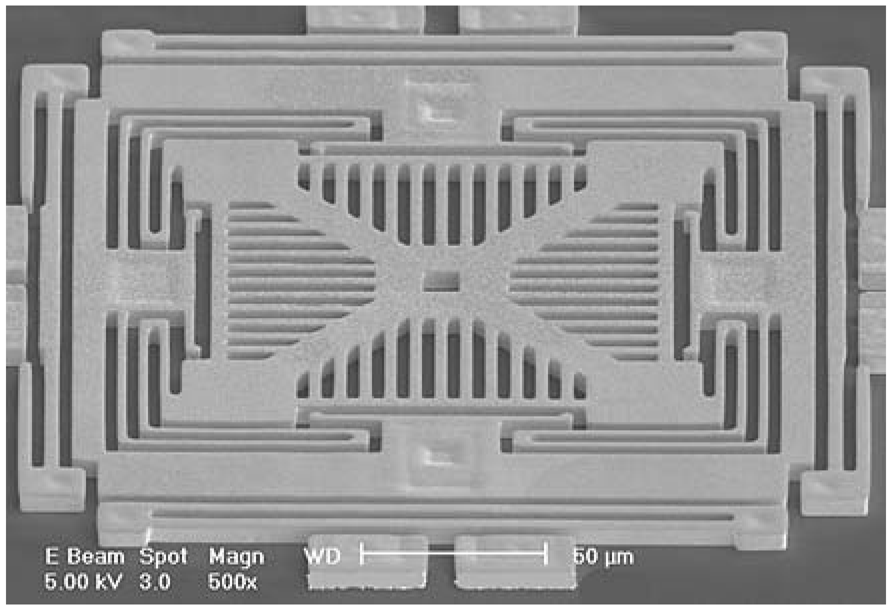
Packaging and Integration

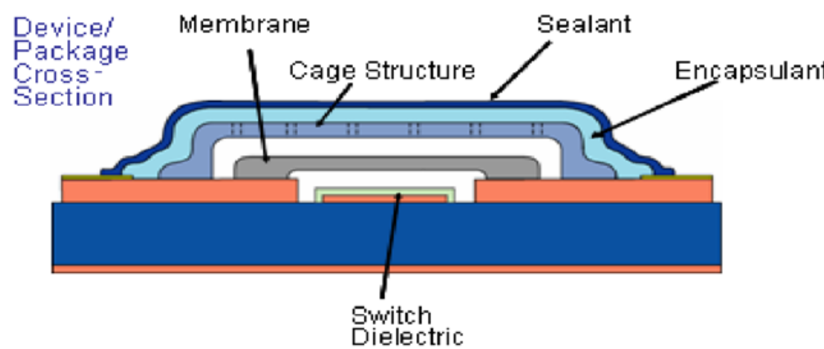
Generally, size matters - *SMALLER IS BETTER!*



Packaging and Integration

MEMS = Micro Electro Mechanical Systems





Summary

•A *transducer converts energy* from one form to another

•A *passive transducer* is called a *sensor*

•Transducer *form* is often influenced by *function* (and *vice-versa*)

•Trend is to have sensor *package as small as possible*

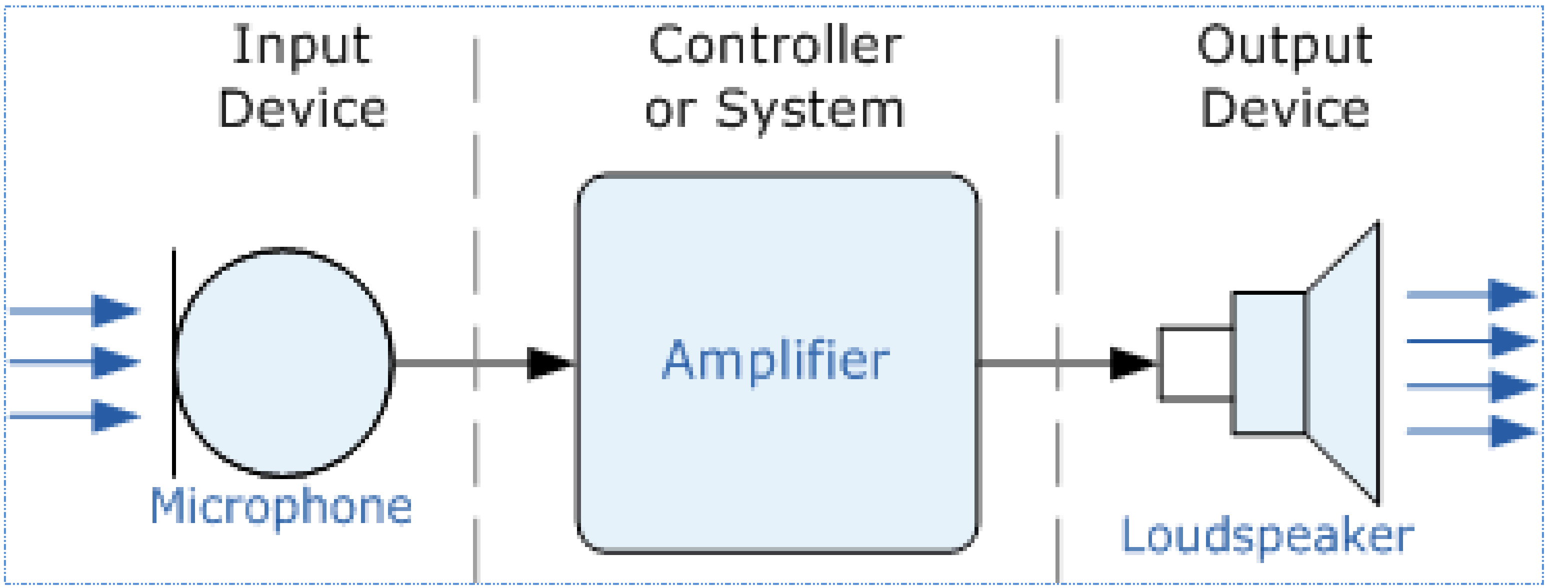
•*MEMS* construction holds promise for *sensor design* and *packaging*

References

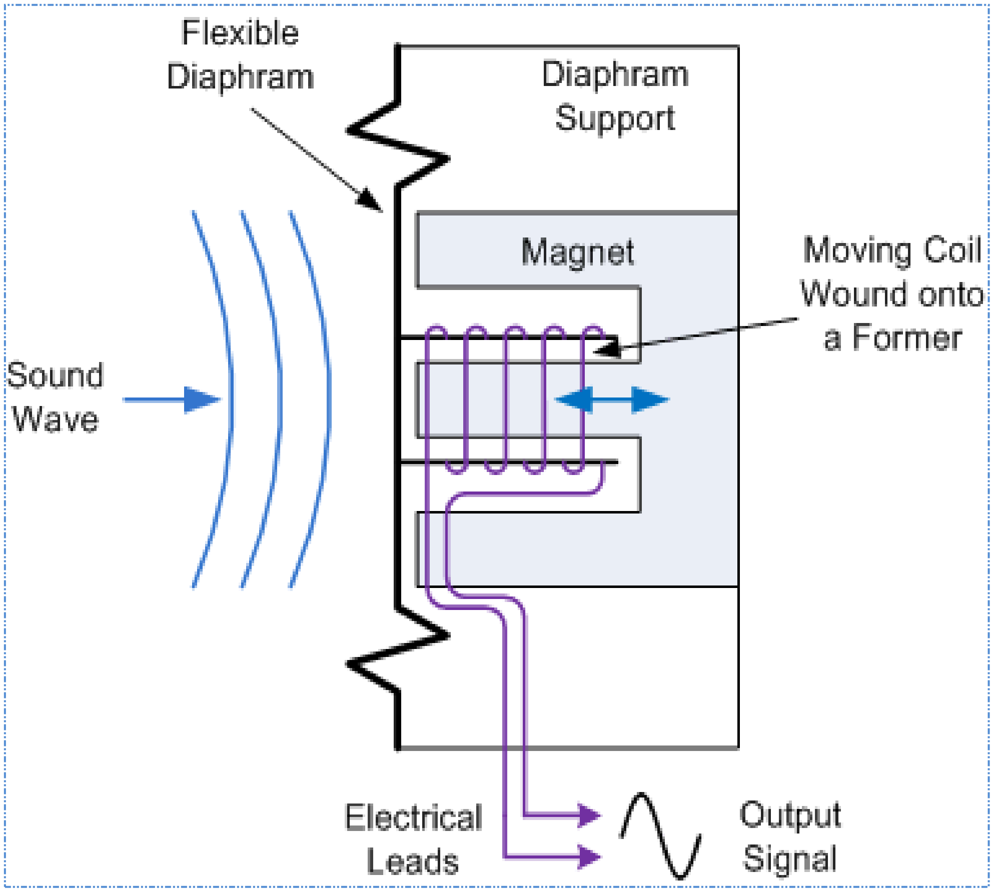
- Brindley, K. “Sensors and Transducers” Heinemann Newnes, 1988.
- Norton, H.N. “Handbook of Transducers” Prentice-Hall, 1989.
- Trietley, H.L. “Transducers in Mechanical and Electronic Design” Marcel Dekker, 1986.
- Ulaby, F.T. “Fundamentals of Applied Electromagnetics” Pearson Prentice Hall, 2004.

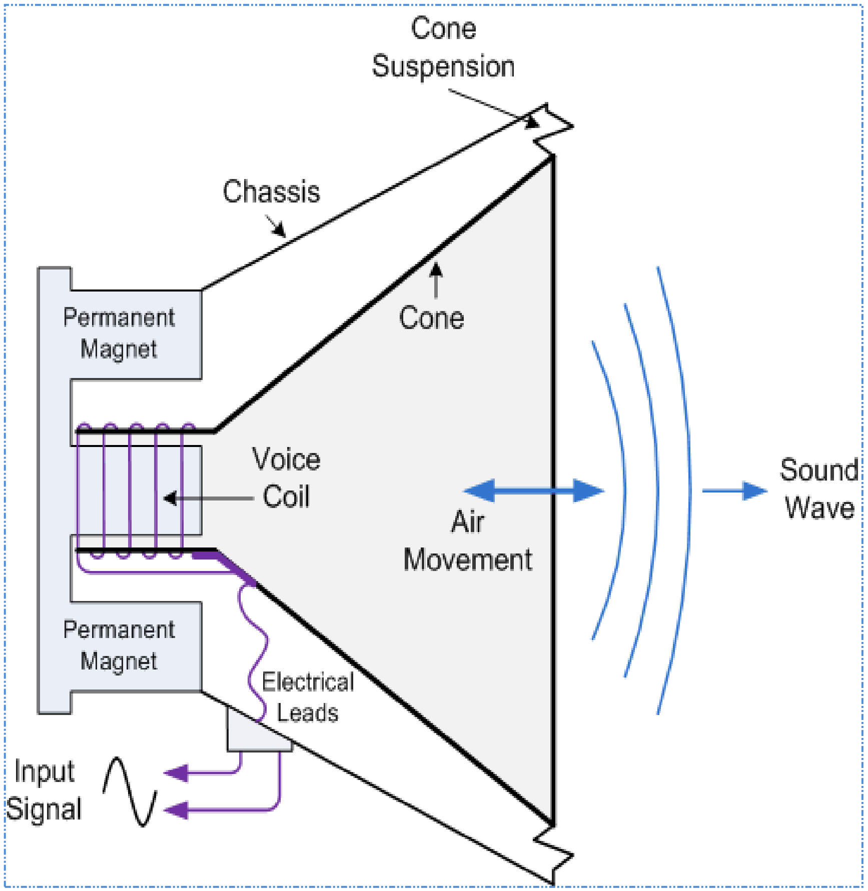
Transducer

- A transducer is a device that converts one type of energy to another.
- The input transducer is called the *sensor*.
- The output transducer is called the *actuator*.



Input and Output Transducers





Basic requirements of a transducers

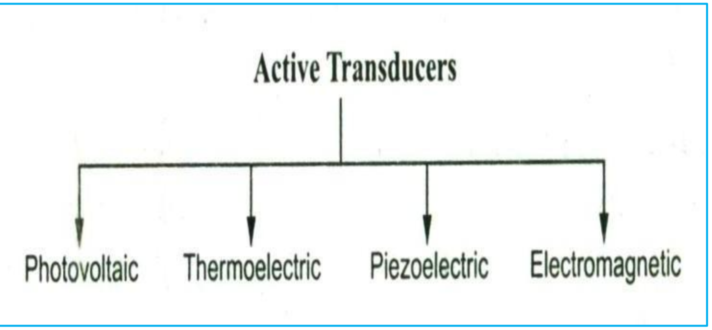
The main function of a transducer is to respond only for the measurement under specified limits for which it is designed.

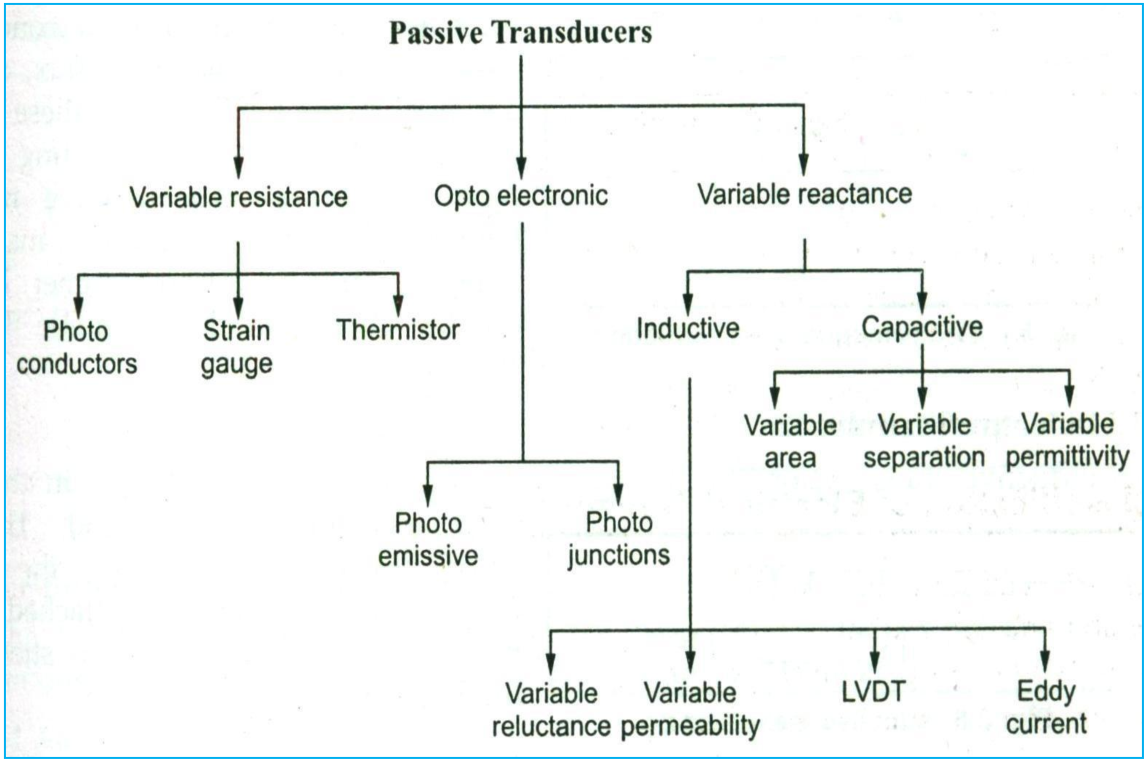
- RUGGEDNESS (Capability of withstanding overload)
- LINEARITY (input – output characteristics should be linear)
- REPEATABILITY (should reproduce same output signal when the same input signal is applied again and again)
- HIGH OUTPUT SIGNAL QUALITY (quality of output signal should be good)
- HIGH RELIABILITY & STABILITY
- GOOD DYNAMIC RESPONSE (output should be faithful to input when taken as a function of time)
- NO HYSTERESIS (should not give any hysteresis during measurement)
- RESIDUAL DEFORMATION (should be no deformation on removal of local after long period of application)

CLASSIFICATON OF TRANSDUCERS

- **PRIMARY AND SECONDARY TRANSDUCERS**
- **ACTIVE AND PASSIVE TRANSDUCERS**
- **ANALOG AND DIGITAL TRANSDUCERS**
- **TRANSDUCERS AND INVERSE TRANSDUCERS**
  (An inverse transducer is a device which that converts an electrical quantity into a non-electrical quantity)

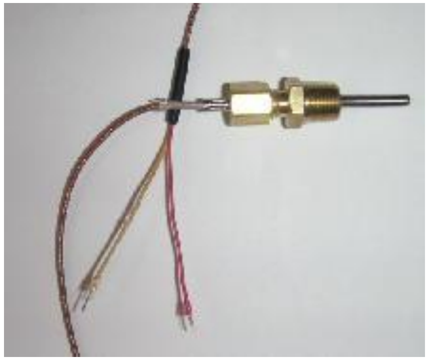
ACTIVE AND PASSIVE TRANSDUCERS





Active and Passive Transducers

- Active Transducers: The output energy of Active Transducers is supplied entirety or almost entirety by its input signal.
- Passive Transducers: Have an auxiliary source of power. This power source is necessary for the operation of passive transducers.

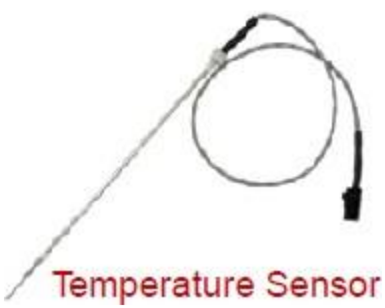


Thermocouple (Active Transducer)

Mic (Passive Transducer)

Primary Sensing Element

- sometimes called pickup, sensor, or transducer.
- It detects the physical variable to be measured,e.g. pressure, temperature, rate of flow, etc. and converts the signal into amore usable form.
- In practice the physical variable is usually transformed into a mechanical or an electrical signal.



Pressure Sensor

Oxygen Sensor

Temperature Measurement

The *International Practical Temperature Scale (IPTS) defines six primary fixed points* for reference temperatures in terms of:

- The triple point of equilibrium hydrogen 259.34◦C
- The boiling point of oxygen 182.962◦C
- The boiling point of water 100.0◦C
- The freezing point of zinc 419.58◦C
- The freezing point of silver 961.93◦C
- The freezing point of gold 1064.43◦C

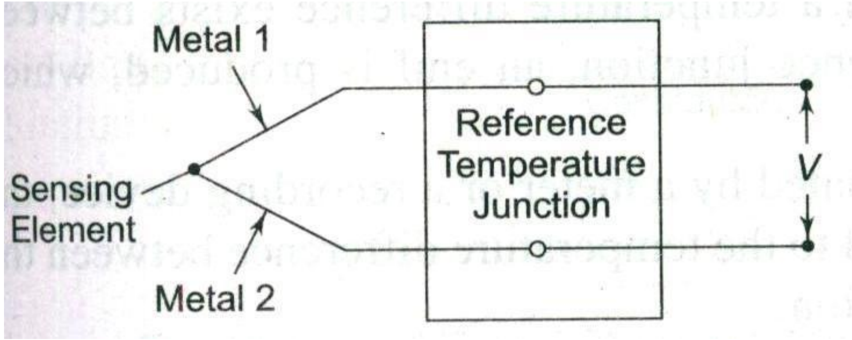
(all at standard atmospheric pressure)

The freezing points of certain other metals are also used as *secondary fixed points to* provide additional reference points during calibration procedures.

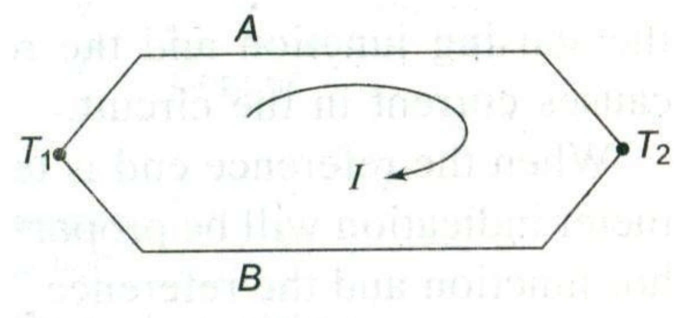
Instruments to measure temperature can be divided into separate classes according to the physical principle on which they operate. The main principles used are:

- The thermoelectric effect
- Resistance change
- Sensitivity of semiconductor device
- Radiative heat emission
- Thermography
- Thermal expansion
- Resonant frequency change
- Sensitivity of fibre optic devices
- Acoustic thermometry
- Colour change
- Change of state of material.

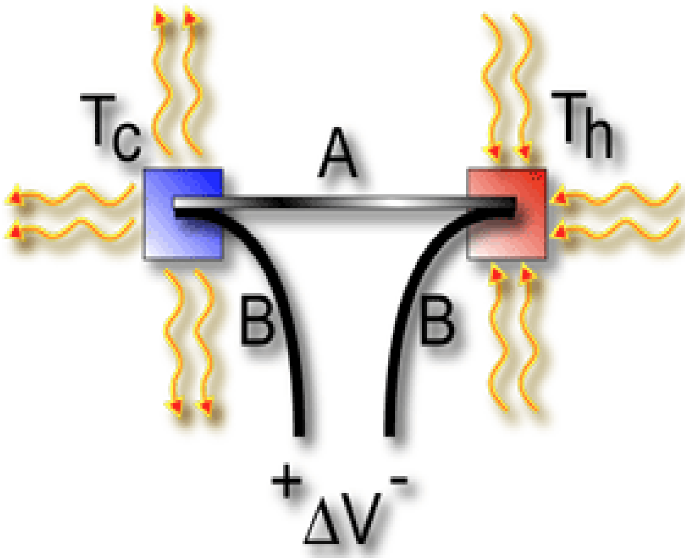
Thermocouple



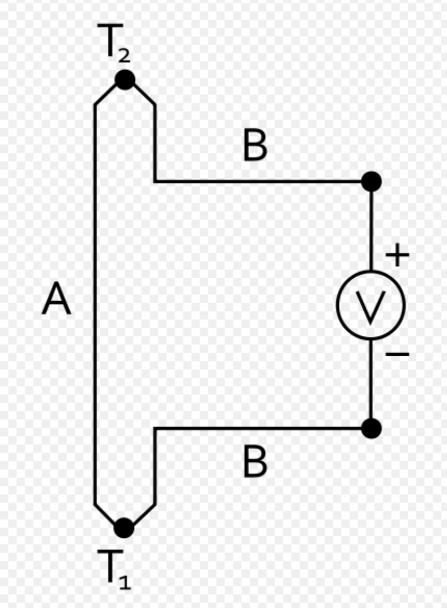
Thermocouple Connection



Current through Two Dissimilar Metals

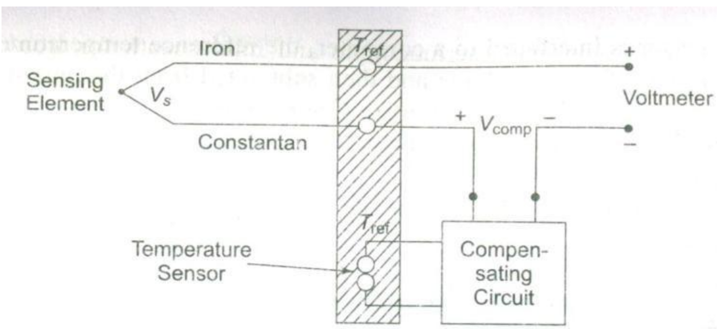


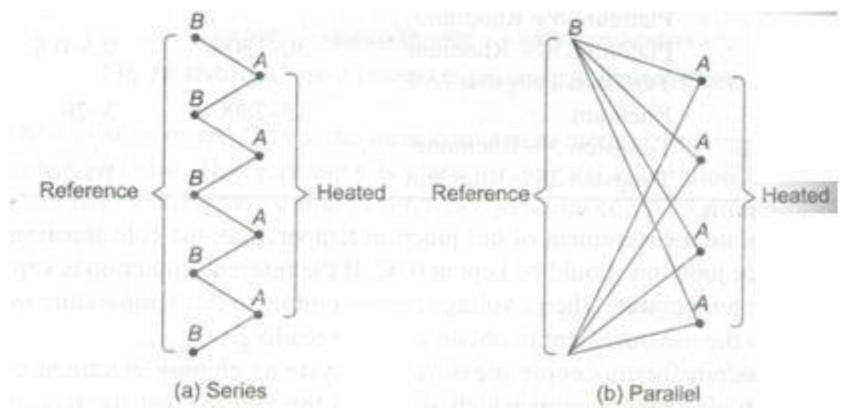
$V = \alpha(T_h - T_c)$

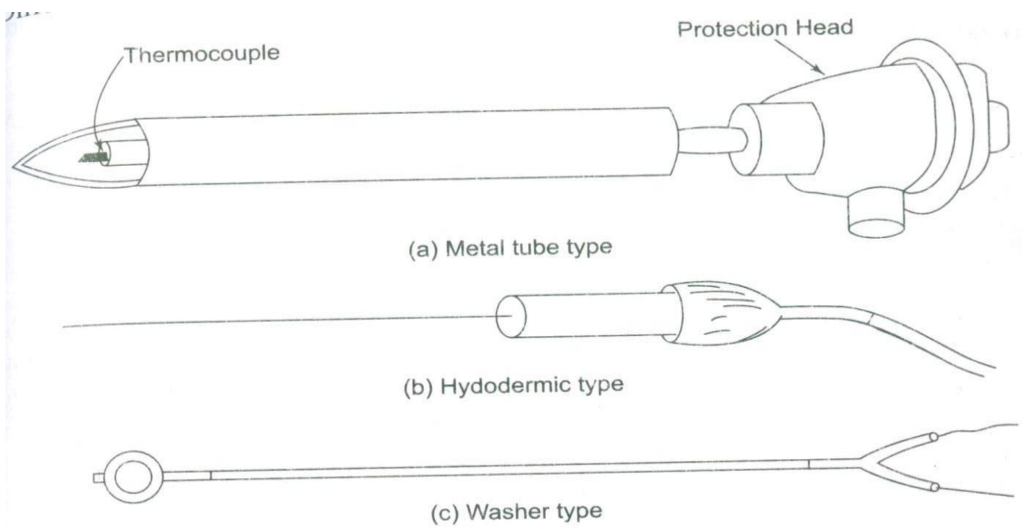


Seebeck Effect Circuit

Different Types of Thermocouples







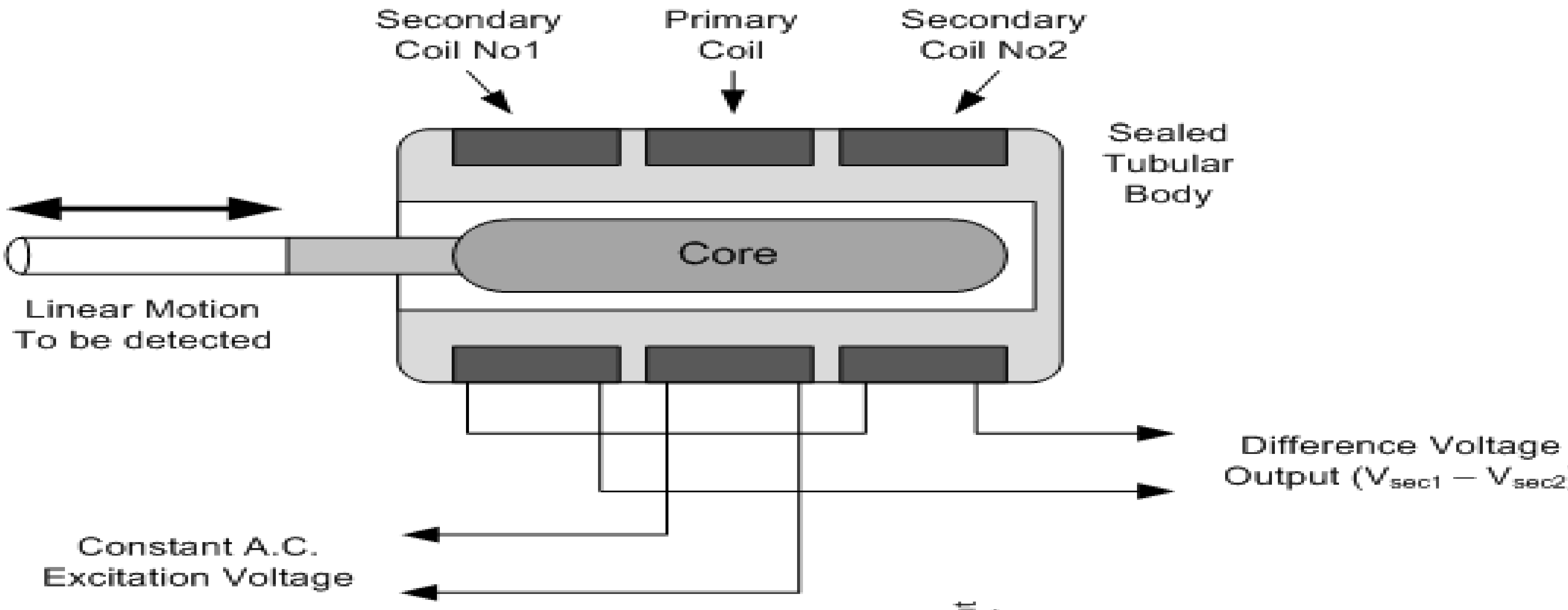
Advantages and Disadvantages of Thermocouples

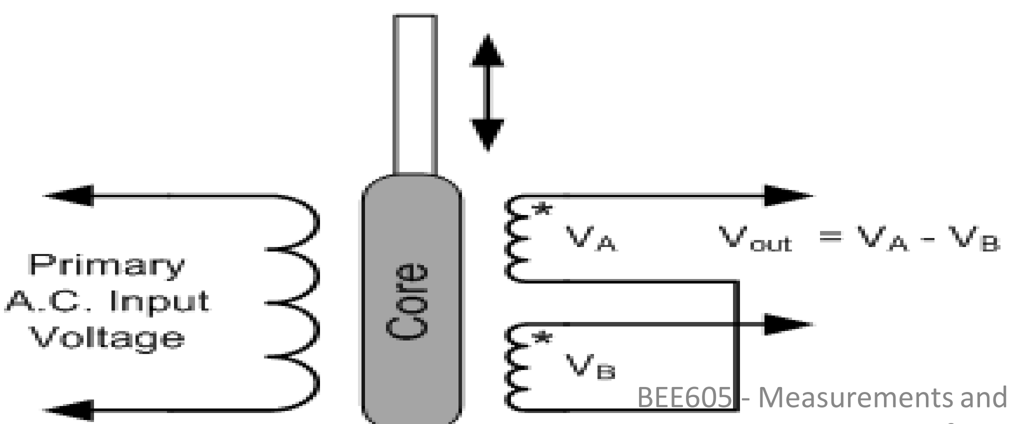
- ✓ Wide temperature range (-270°C to 2700°C
- ✓ Rugged Construction
- ✓ Bridge Circuits not required for temperature measurement.
- ✓ Comparatively cheaper in cost
- ✓ Good reproducibility
- ✓ Speed of response is high compared to thermometer systems.
- ✓ Calibration checks can be easily performed
- ✓ Using extension leads and compensating cables, long distance transmission for temperature measurement is possible.
- ✓ Good Accuracy

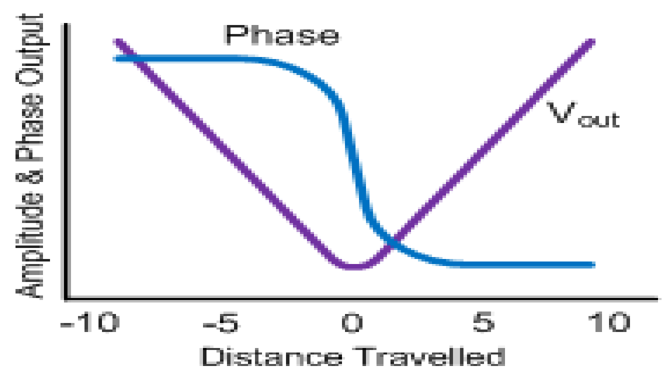
- ❖ Compensation circuits is essential for accurate measurements
- ❖ They exhibit non-linearity in the emf versus temperature characteristics.
- ❖ Many applications needs signal amplifications.
- ❖ Proper separation of extension leads from thermocouple is required to avoid stray electrical signal pickup.

Linear Variable Differential Transformer

Three Coil mutual inductance device (LVDT)



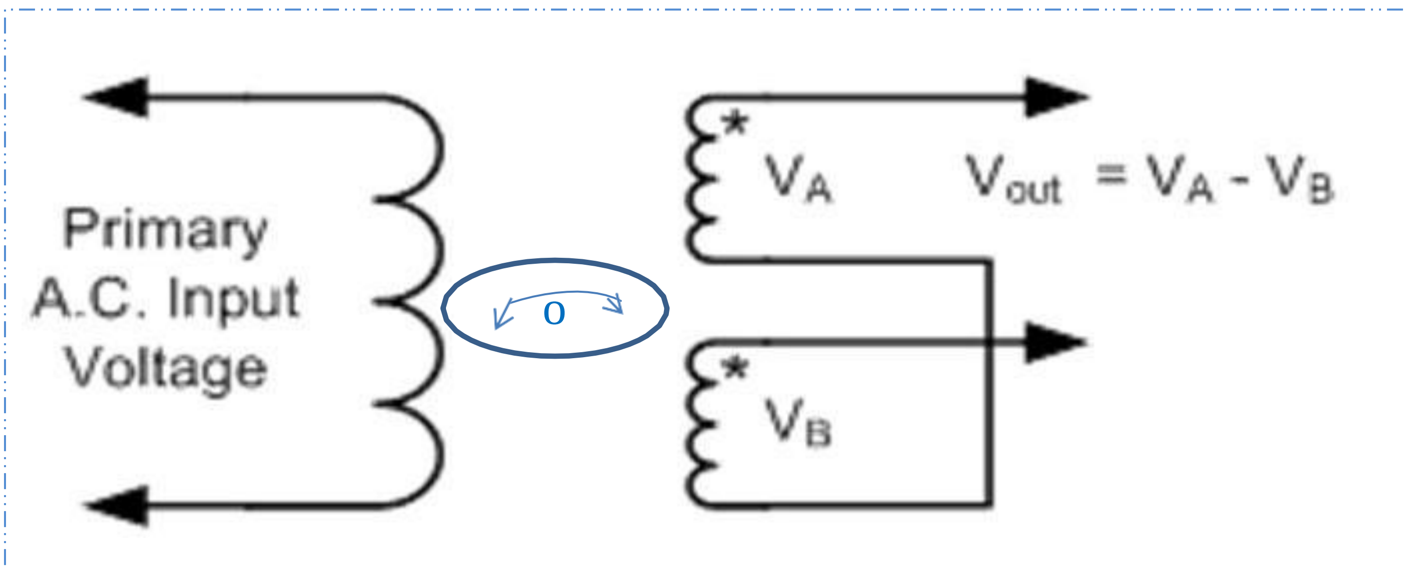




Rotary Variable Differential Transformer

A RVDT is a type of electrical transformer used for measuring Angular Displacement .

The RVDT construction is similar in construction to LVDT, except that a cam-shaped core replaces the core in the LVDT as shown below.



Capacitive Transducers

The principle of these type is that variations in capacitance are used to produce measurement of many physical phenomenon such as dynamic pressure, displacement, force, humidity, etc.

An equation for capacitance is

$$C = \frac{0.088KA(N-1)}{d} \text{ Pico farads}$$

Where K= dielectric constant (for air K=1),

A= area of one side of one plate,

N= Number of plates,

d= Separation of plate surfaces (cm)

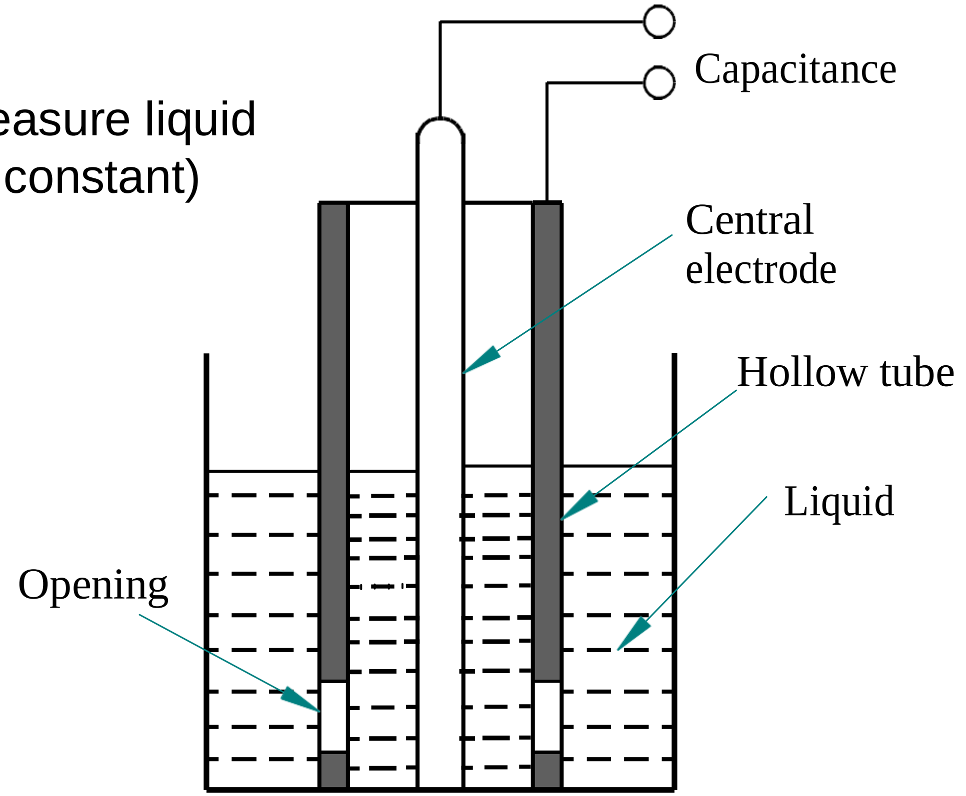
Capacitance is the ability of a body to hold an electrical charge.

Capacitance is also a measure of the amount of electric charge stored for a given electric potential. A common form of charge storage device is a two-plate capacitor. If the charges on the plates are +Q and −Q, and V gives the voltage between the plates, then the capacitance is given by C=(Q/V)

The SI unit of capacitance is the farad; 1 farad = 1 coulomb per volt

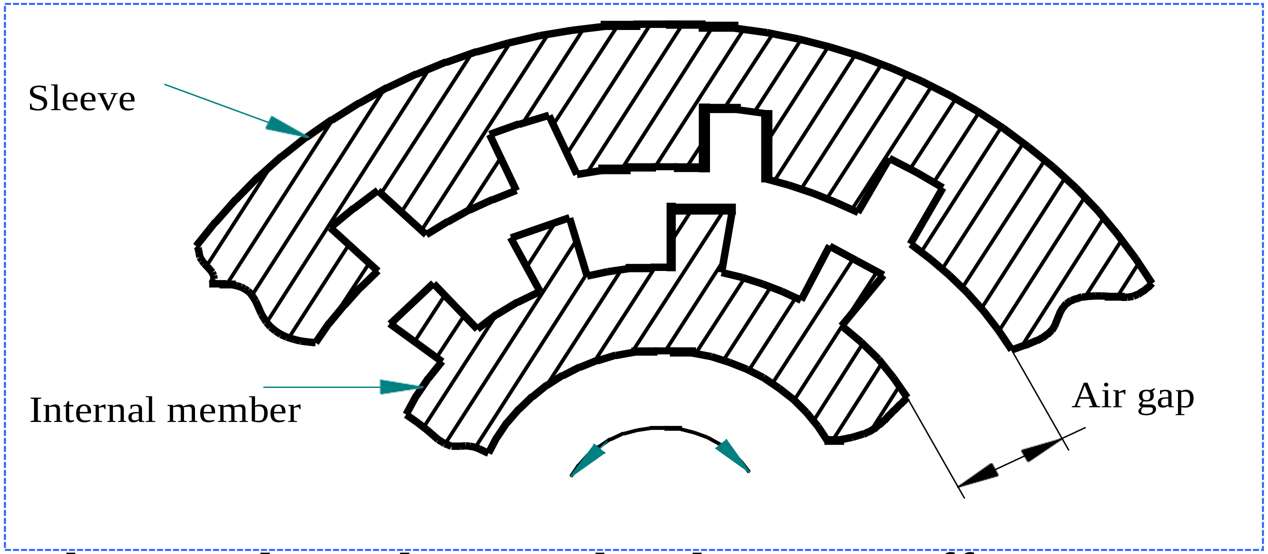
Capacitive Transducer

Capacitance Pickup to measure liquid level (Changing dielectric constant)



The above fig. shows a device used for the measurement of liquid level in a container. The capacitance between the central electrode and the surrounding hollow tube varies with changing dielectric constant brought about by changing liquid level. Thus the capacitance between the electrodes is a direct indication of the liquid level. Variation in dielectric constant can also be utilized for measurements of thickness, density, etc.

Capacitive Transducer (Torque meter)

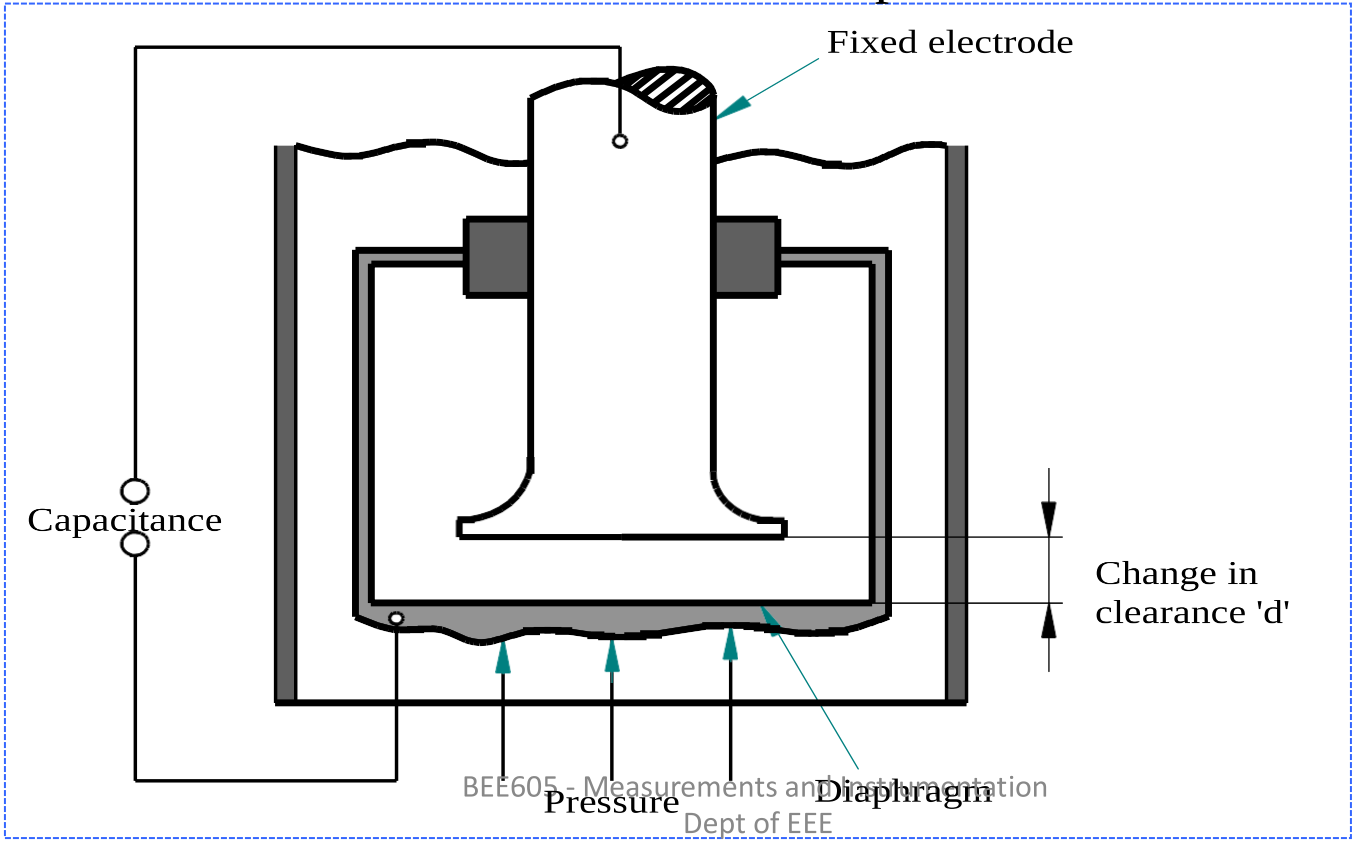


Capacitance changes depending on the change in effective area. This principle is used in the secondary transducing element of a *Torque meter*. This device uses a sleeve with serrations cut axially and a matching internal member with similar serrations as shown in the above fig.

Torque carried by an elastic member causes a shift in the relative positions of the serrations, thereby changing the effective area. The resulting capacitance change may be calibrated to read the torque directly.

Capacitive Transducer
(Capacitive Type Pressure Transducer)

The capacitance varies inversely as the distance between the plates. The fig shows a capacitive type pressure transducer where the pressure applied to the diaphragms changes the distance between the diaphragm & the fixed electrode which can be taken as a measure of pressure.



Advantages of Capacitive Transducers

(1) Requires extremely small forces to operate and are highly sensitive

(2) They have good frequency response and hence useful for dynamic measurements.

(3) High resolution can be obtained.

(4) They have high input impedance & hence loading effects are minimum.

(5) These transducers can be used for applications where stray magnetic fields render the inductive transducers useless.

Disadvantages of Capacitive Transducers

(1) Metallic parts must be properly insulated and the frames must be earthed.

(2) They show nonlinear behaviour due to edge effects and guard rings must be used to eliminate this effect.

(3) They are sensitive to temperature affecting their performance.

(4) The instrumentation circuitry used with these transducers are complex.

(5) Capacitance of these transducers may change with presence of dust particles & moisture.

Thank You

SENSORS and TRANSDUCERS

Tadeusz Stepinski, Signaler och system

- INTRODUCTION
  - Course presentation
  - Classification of transducers
  - Transducer descriptions
  - Transducer parameters, definitions and terminology
  - Transducer effects in silicon and other materials

SENSORS and TRANSDUCERS

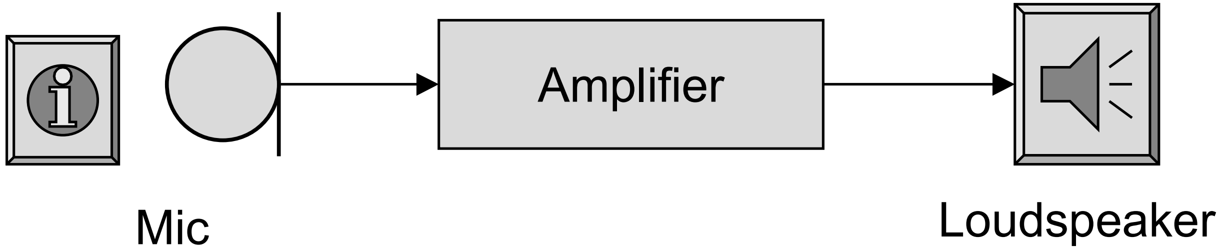
- Course presentation
  - Classification and descriptions of transducers
  - Survey of possible energy conversions
    - Optical, mechanical, thermal, magnetic and chemical
  - Sensor characteristics
  - Sensor compensation

SENSORS and TRANSDUCERS

SENSORS convert energy information

One energy form must be converted into the same or another energy form with exactly the same information content as the originating energy form

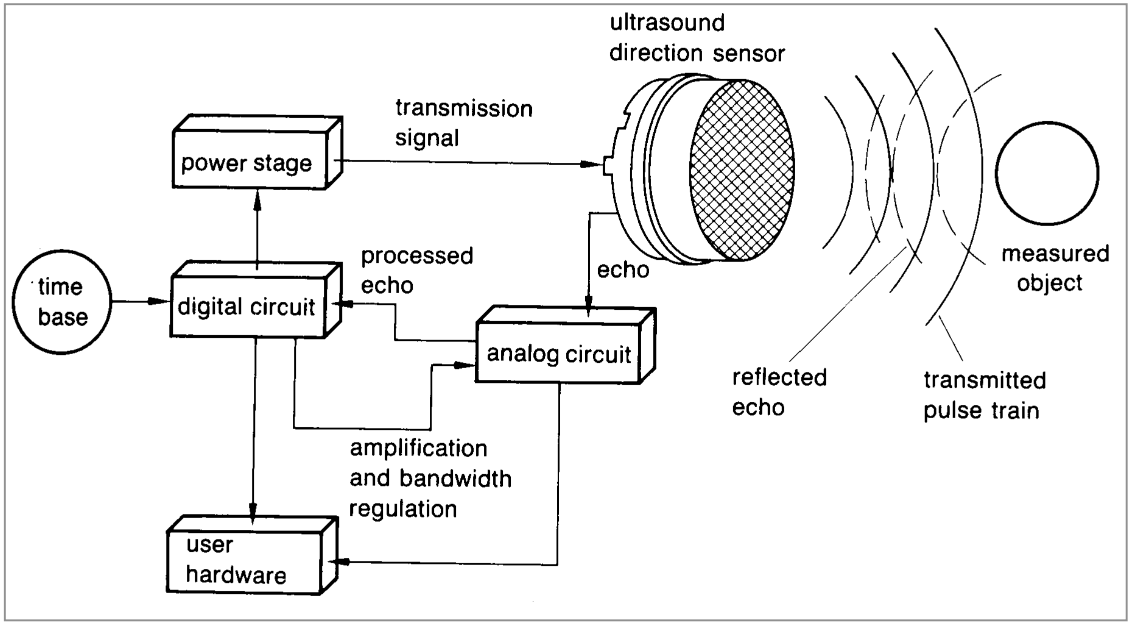
Example:



SENSORS and TRANSDUCERS

SENSORS use some form of energy to get the information

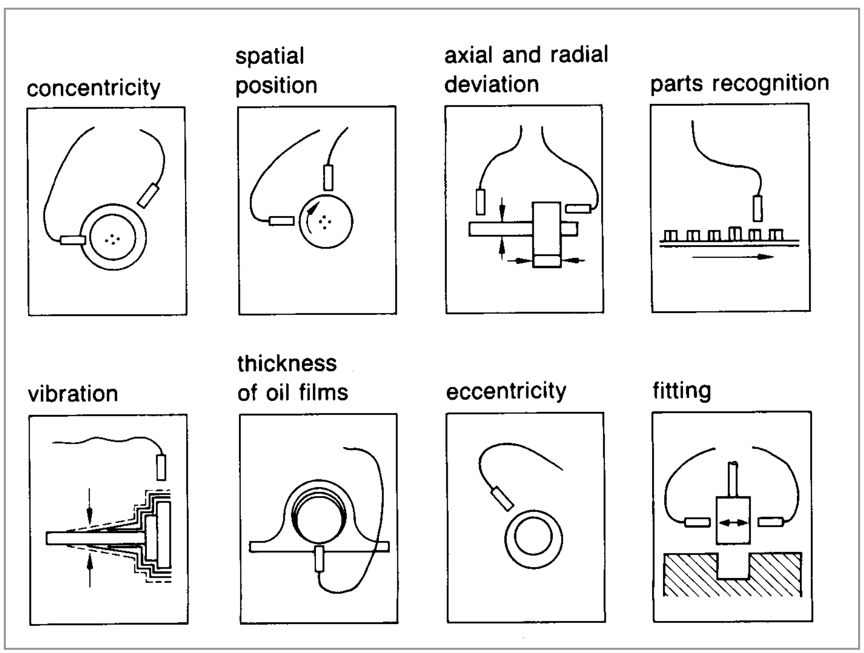
Example: Ultrasonic distance measurement

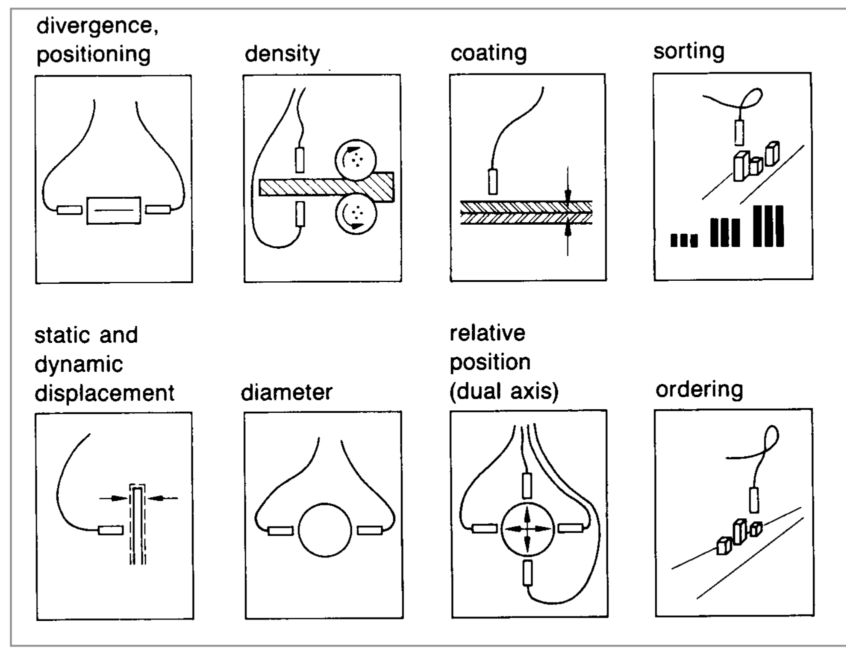


SENSORS and TRANSDUCERS

One form of energy can be used for measuring different quantities

Example: Applications of inductive sensors



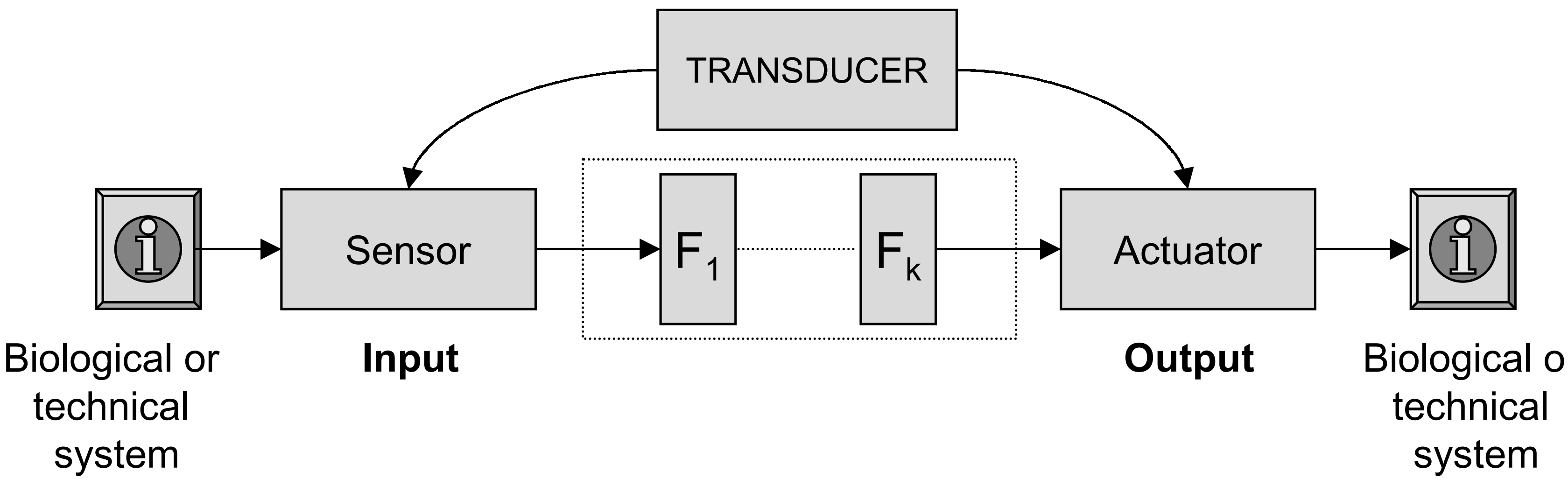


SENSORS and TRANSDUCERS

TRANSDUCER - *latin tranducere* - ‘to convert’

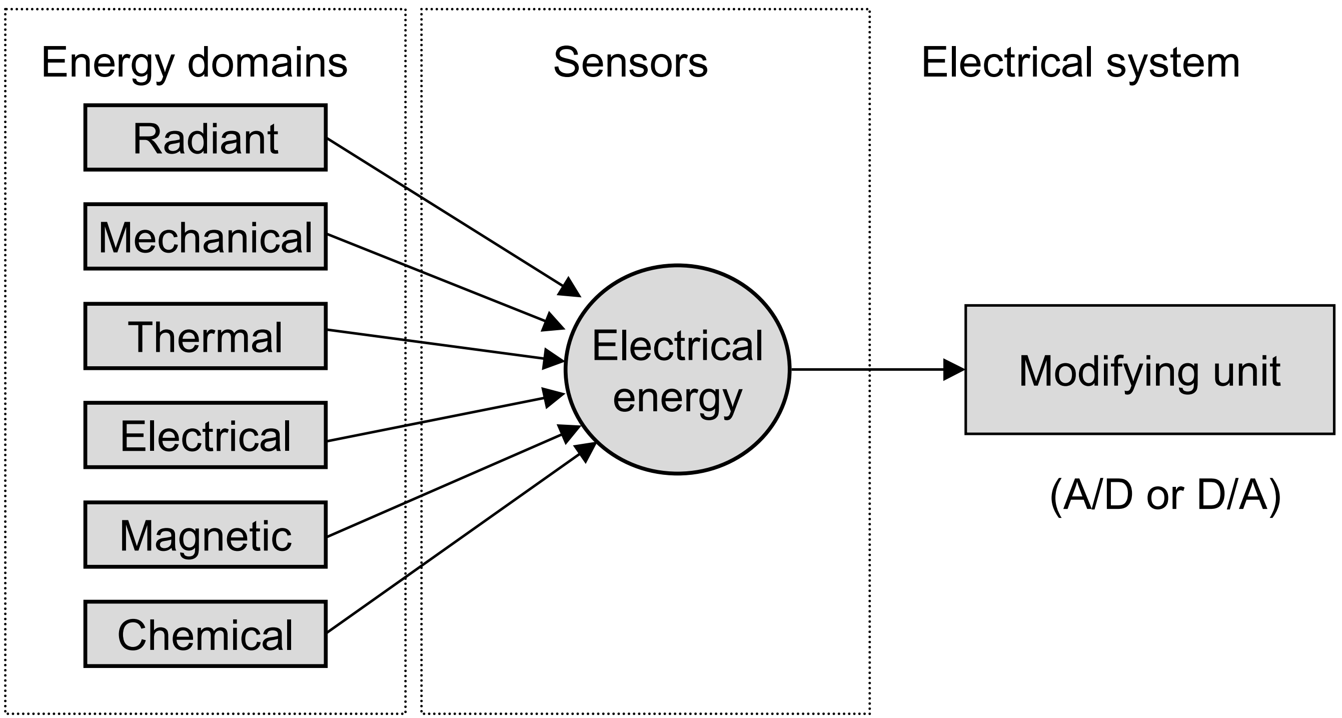
Input transducer - sensor

Output transducer - actuator



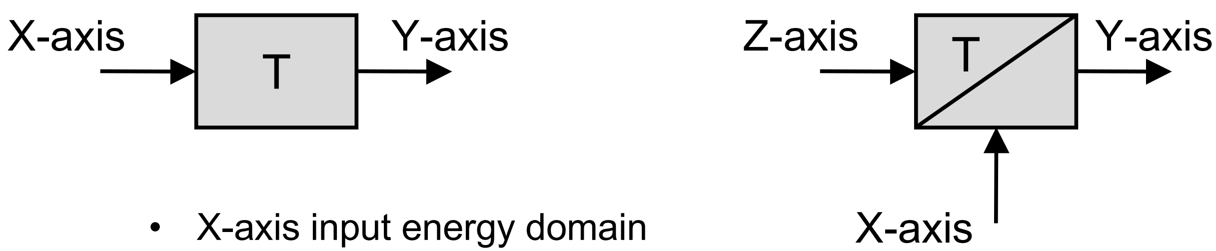
Classification of transducers

⁕ Types of energy form



Classification of transducers

- Modulating and self-generating transducers
  - Modulating transducer requires an auxiliary energy source
    - Strain gauge, thermal resistor, liquid-crystal-display
  - Self-generating transducer requires no auxiliary energy source
    - Solar cell, thermocouple, piezoelectric element



- X-axis input energy domain
- Y-axis output energy domain
- Z-axis modulating energy domain

Classification of transducers

- Miller index - three dimensional vector

  [x y z] ⇒ [*input energy, output energy, modulating energy*]

Transducer	Miller index [x y z]	Type description
Transistor	[el, el, el]	Modulating shape transducer
Thermocouple	[th, el, 00]	Self-generating input transducer
pH meter	[ch, el, 00]	Self-generating input transducer
LED display	[el, ra, 00]	Self-generating output transducer
LCD display	[ra, ra, el]	Modulating output transducer
Coil	[ma, el, 00]	Self-generating output transducer
Magnetoresistor	[ma, el, el]	Modulating input transducer
Photoconductor	[ra, el, el]	Modulating input transducer

State description of transducers

⁕ The steady state description - reveals characteristics of transducers

Note! No transducer is sensitive to one physical energy only

Consider a small volume dV in which transducer is placed

The energy content dW in this volume contains the summation of all possible energies

$$dW = \sum I_i e_i = \sigma \cdot dl + P\frac{\partial\rho}{\rho} + V \cdot dq + E \cdot dD + H \cdot dB + T \cdot dS + w_r$$

I_i - intensive quantity (can carry power, e.g., force, pressure, voltage)

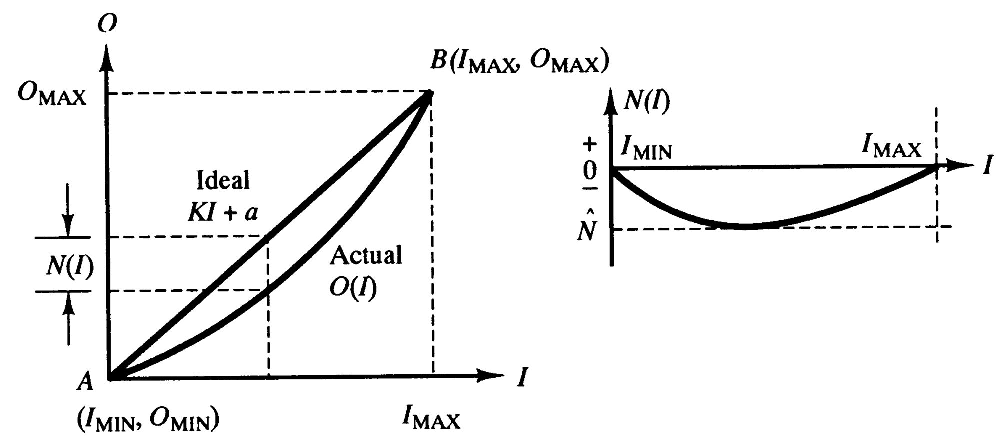
e_i - extensive quantity (cannot curry power, e.g.,displacement, resistance)

σ - mechanical force	dl - displacement
P - pressure	dρ - volume density of mass
V - voltage	dq- volume density of charge
E - electrical field	dD- charge per unit surface
H - magnetic field	dB - magnetic induction
T - absolute temperature	dS - entropy per unit volume
	w_r - radiation per unit volume

Static Characteristics

- Systematic Characteristics
  - Range - min and max values of input or output variables
    - Example: input range 100 -250°C or output range 4 to 20 mA
  - Span - maximum variation of input or output
    - Example: 150 °C or 16 mA
  - Linearity - input values *I* and output values *O* lie on a straight line

$$O_{ideal} = KI + a \qquad K = \frac{O_{\max} - O_{\min}}{I_{\max} - I_{\min}}$$



  - Nonlinearity

$$N(I) = O(I) - (KI + a)$$

Dynamic Characteristics

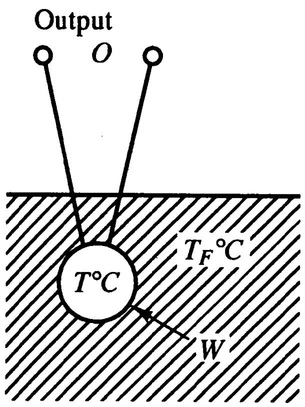
- Transfer functions
  - First order elements
    - Example: *Temperature sensor is described by heat balance equation*

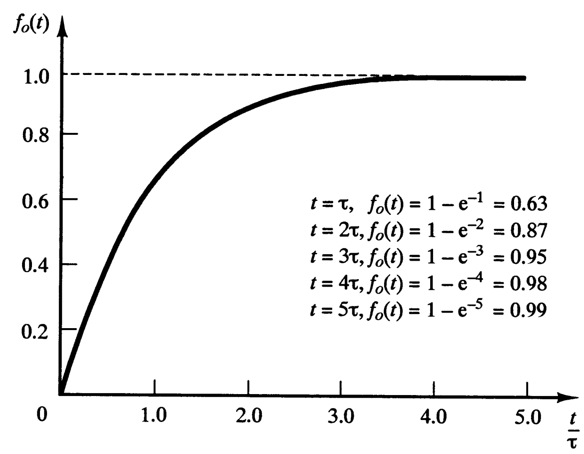
$$\tau \frac{dT}{dt} + T = T_F \quad \Rightarrow \quad G(s) = \frac{1}{1+\tau s}$$

where: τ - time constant

T- sensor temperature

T_F- ambient temperature





Dynamic Characteristics

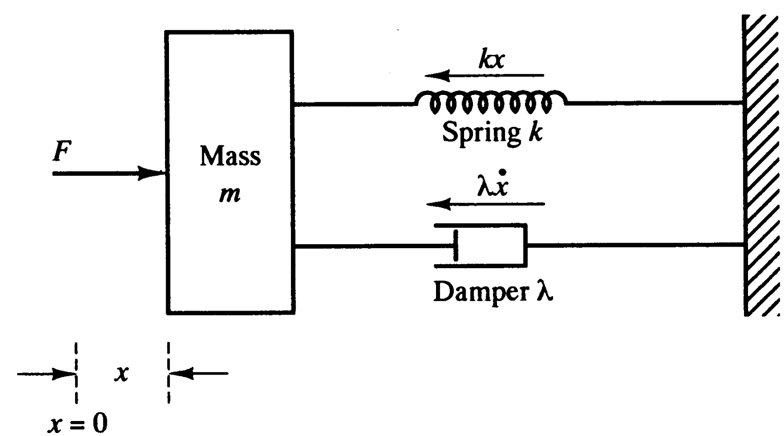
- Transfer functions
  - Second order elements
    - Example: *Mass-spring-damper (accelerometer)*

$$\frac{1}{\omega_n}\frac{d^2x}{dt^2}+\frac{2\xi}{\omega_n}\frac{dx}{dt}+x=\frac{1}{k}F \quad\Rightarrow\quad G(s)=\frac{1}{\frac{1}{\omega_n^2}s^2+\frac{2\xi}{\omega_n}s+1}$$

where:

$\omega_n=\sqrt{\frac{k}{m}} \quad rad/\sec$ - undamped natural frequency

$\xi=\frac{\lambda}{2\sqrt{km}}$ - damping ratio



Transducer parameters

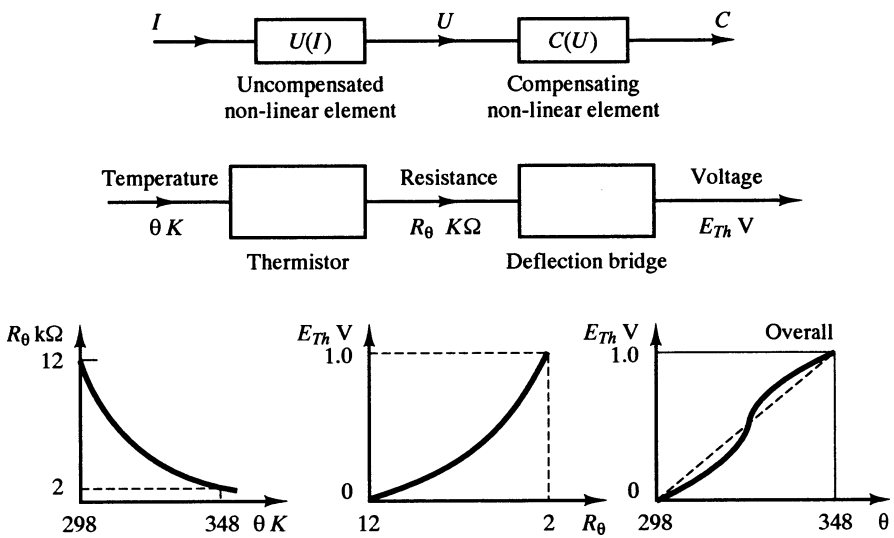
* *The state description - Example*

Parameter	Unit	Description
Settling (response) time	s	Time for signal to respond to step input signal within a rated accuracy
Rise time	s	Time for signal to change from 10% to 90% of its p-p value
Excitation	V or A	Power supply voltage/current required for normal operation
Sensitivity	dV/dx_i	The rate of change at the output at the change at the input
Hysteresis	any	Permanent deviation from zero for zero input
Offset voltage	mV	Output voltage obtained for zero (reference) input conditions
Temperature coefficient	ppm K^{-1}	The rate of change of reading as a function of temperature
Repeatability	%	Measure of agreement between successive measurement (same conditions)
Reproducibility	%	Measure of agreement between successive measurement (changed conditions)
Temperature range	T(K)	Operating span for specified accuracy

Static errors - error reducing techniques

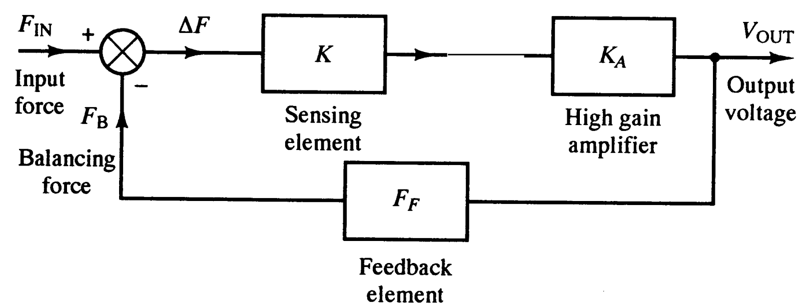
Compensating non-linear element

$$V_{out} = Kk_{cor}F_{in}$$



High gain negative feedback

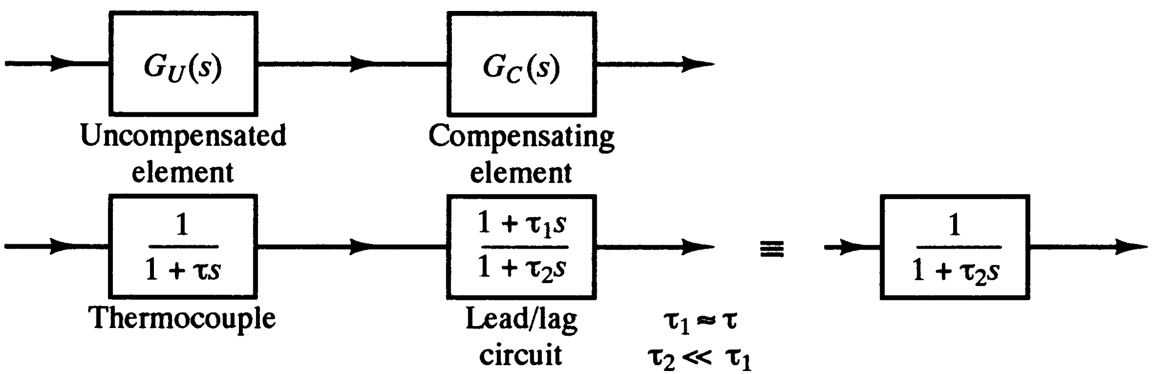
$$V_{out} = \frac{Kk_A}{1 + Kk_A k_F} F_{in} \approx \frac{1}{k_F} F_{in} \qquad if \quad Kk_A k_F >> 1$$



Dynamic errors - Compensating techniques

* Open-loop dynamic compensation

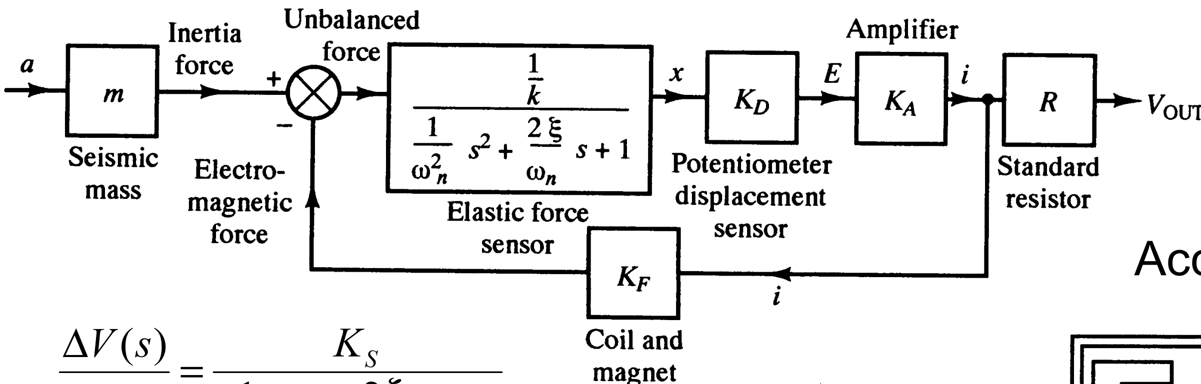
$$V_{out}(\omega) = G_u(\omega) G_c(\omega) F_{in}(\omega)$$



Dynamic errors - Compensating techniques

* High gain negative feedback

$$V_{out}(\omega) = \frac{G(\omega)G_A(\omega)}{1+G(\omega)G_A(\omega)G_F(\omega)} F_{in}(\omega) \approx \frac{1}{G_F(\omega)} F_{in}(\omega) \qquad for \qquad \omega_{\min} < \omega < \omega_{\max} \quad |G(\omega)G_A(\omega)G_F(\omega)| >> 1$$

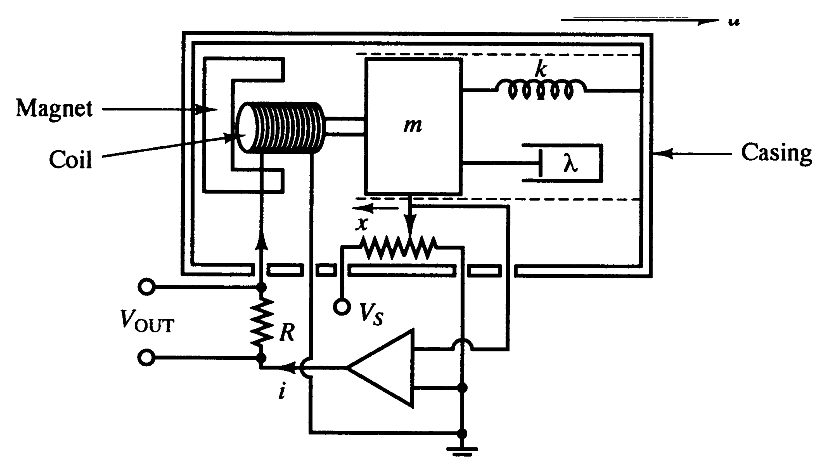


$$\frac{\Delta V(s)}{\Delta a(s)} = \frac{K_S}{\frac{1}{\omega_{ns}^2}s^2 + \frac{2\xi_S}{\omega_{ns}}s + 1}$$

$$\omega_{ns} = \omega_n \sqrt{\frac{K_A K_D K_F}{k}}$$

$$\xi_S = \xi \sqrt{\frac{k}{K_A K_D K_F}}$$

Accelerometer



Definitions and terminology

- ***Biophotonics*** *- application of photonic technology in medical or biotechnology products*
- ***Biosensor*** *- sensor for the measurements of ion concentrations in living systems or in organic compounds*
- ***Mechatronics*** *- discipline that combines mechanical and electronic components into al larger functional unit*
- ***Micromechanics*** *- the design, the development and the production of extremely small mechanical devices*
- ***Optoelectronics*** *- discipline combining optics or photonics and electronics on one device*
- ***Smart sensor*** *- single-chip functional unit combining sensing and processing functions*

Transducer effects in silicon and other compatible materials

- *Transducer effects in silicon - electrons are the information carrier*

I/Out		Modulating			
Energy domain	Self-generating	Resistor, inductance, capacitive	Diode	Transistor	Examples of smart transducers
Radiation	Volta effect, solar cell	Photoconductor	Photodiode	Phototransistor	Photo-IC CCD
Mechanical	Not known	Piezoresistivity	Piezojunction	Piezotransistor	Accelerometer Piezo IC
Thermal	Seebeck effect, thermocouple	R = f(T)	Reverse biased I_{rev}= f(T)	Forward biased U_{BE}= f(T)	Temeperature IC
Electrical	Thermal energy, resistance	Electric field MOSFET	Electric field FET	Dual gate MOSFET	All types of IC
Magnetic	Maxwell diffused coil	Magnetoresistor	Magnetic diode	Hall effect	Hall IC
Chemical	Galvanic	Ion concentration	Not known	ISFET	Smart nose

Review Questions

- Describe difference between modulating and self-generating transducers
- Define type and Miller index for
  - termistor
  - TV screen
  - Loudspeaker
- Give an example of self-generating sensor for thermal energy
- Give an example of modulating sensor for magnetic energy
- Derive transfer function for a temperature sensor
- Derive transfer function for a mass-spring-damper
- Describe the principle of compensation using open-loop correction
- Describe the principle of compensation using high gain negative feedback for
  - static characteristics
  - dynamic characteristics

Chapter 5. Biopotential Electrodes

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ÇANKAYA ÜNİVERSİTESİ

MEKATRONİK MÜHENDİSLİĞİ BÖLÜMÜ

Biopotential Electrodes

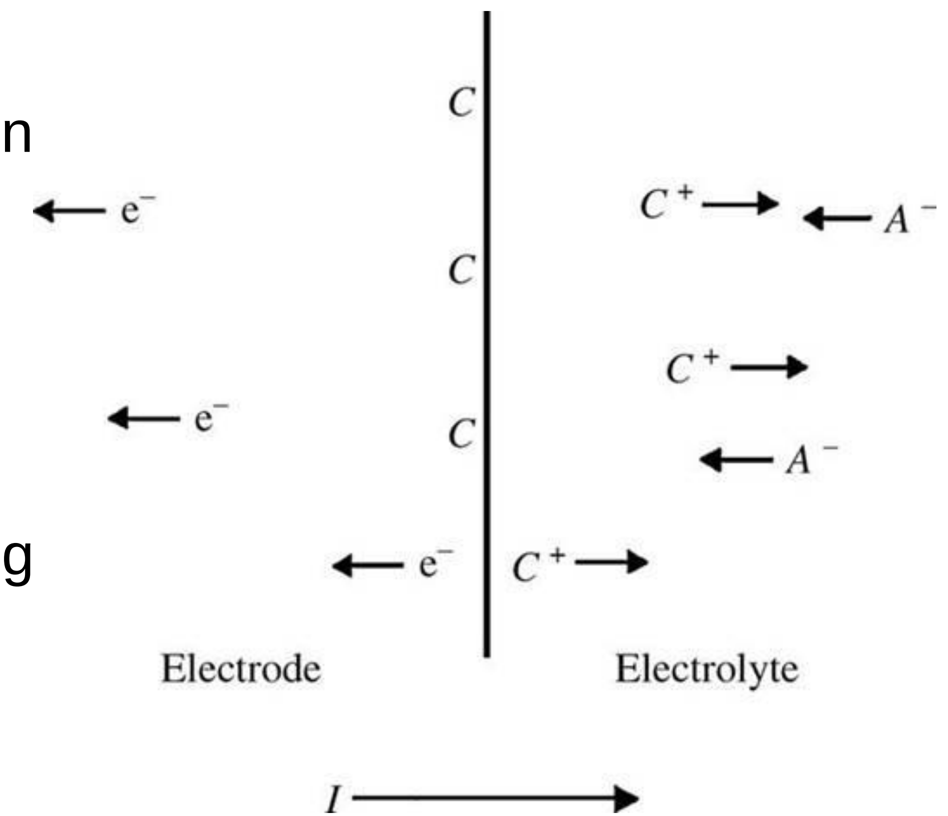
- Interface between the body and the electronic measuring apparatus to measure and record potentials.
- Biopotential electrodes conduct current across the interface between the body and the electronic measuring circuit, as other potential measurement devidces do.
- Electrode carries out a transducing function, because current is carried in the body by ions, whereas it is carried in the electrode and its lead wire by electrons.
- Electrode serve as a transducer to change an ionic current into an electronic current.
- Electrodes have electrical characteristics and can be modelled with equvialent circuits based on this characteristics.

Electrode-Electrolyte interface

- To understand the passage of electric current from the body to an electrode, electrode-electrolyte interface is examined.

The faradaic current is the current generated by the reduction or oxidation of some chemical substance at an electrode.

- A net current, I, that crosses the interface, passing from the electrode to the electrolyte, consists of
- (1) electrons moving in a direction opposite to that of the current **in the electrode**,
- (2) cations (denoted by C^+) moving in the same direction as the current, and
- (3) anions (denoted by A^-) moving in a direction opposite to that of the current **in the electrolyte**.



- For charge to cross the interface—***there are no free electrons in the electrolyte*** and ***no free cations or anions in the electrode***—

$$C \rightleftarrows C^{n+} + ne^{-}$$

where *n* is the valence of *C.*

Assumption:

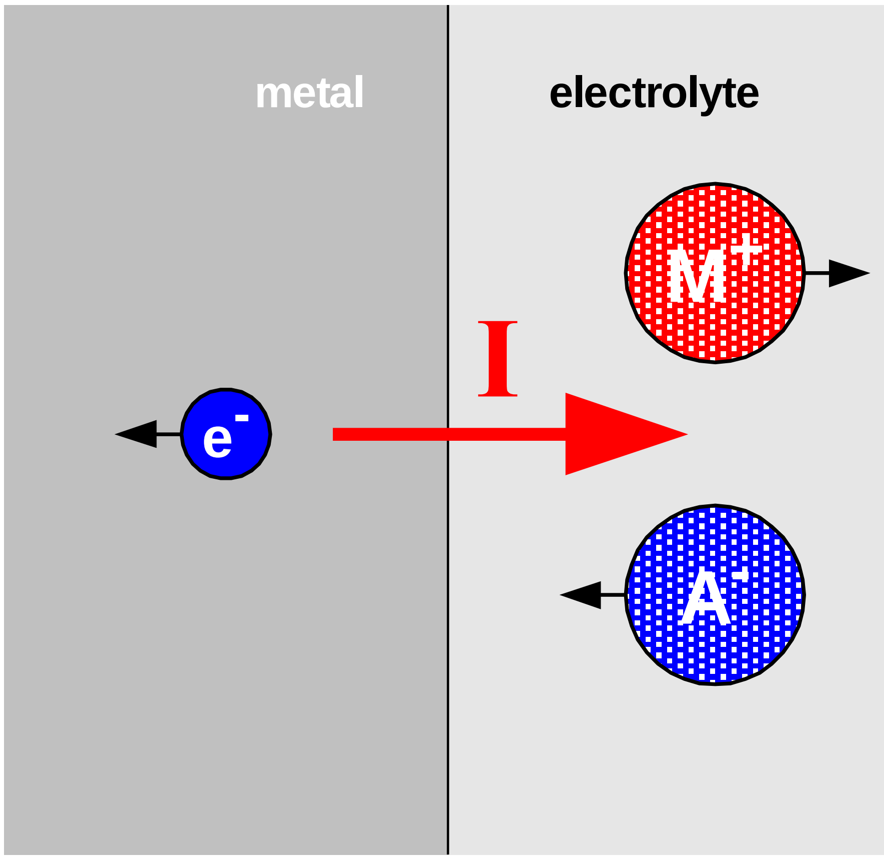
- The electrode is made up of some atoms of the same material as the cations and that this material in the electrode at the interface can become oxidized to form a cation and one or more free electrons
- The cation is discharged into the electrolyte; the electron remains as a charge carrier in the electrode.

$$A^{m-} \rightleftarrows A + me^{-}$$

and *m* is the valence of *A*

- an anion coming to the electrode–electrolyte interface can be oxidized to a neutral atom, giving off one or more free electrons to the electrode.

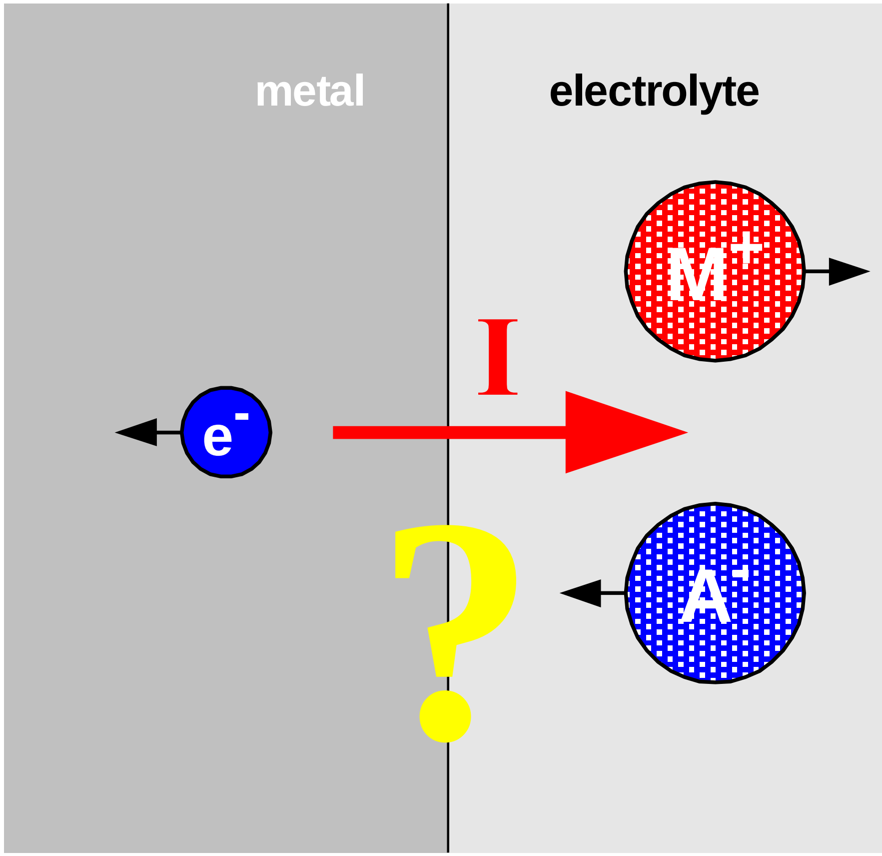
Electrode-Electrolyte interface



To sense a signal
a current **I must flow** !

www.vyssotski.ch/BasicsOfInstrumentation/Electrodes.ppt

Electrode-electrolyte Interface problem



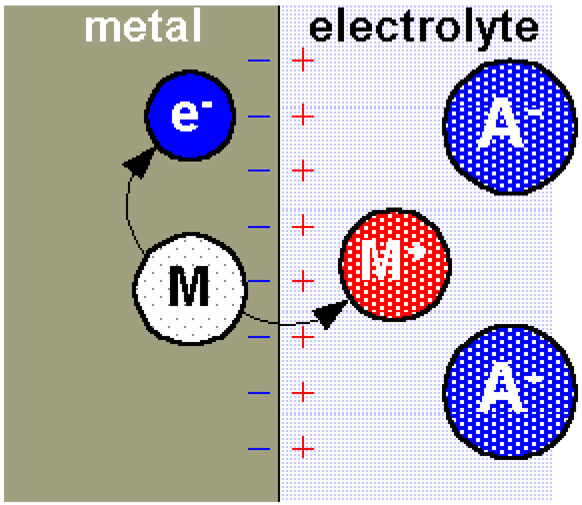
To sense a signal
a current **I must flow** !

But no electron **e^-** is passing the interface!

metal cation

leaving into the electrolyte

No current



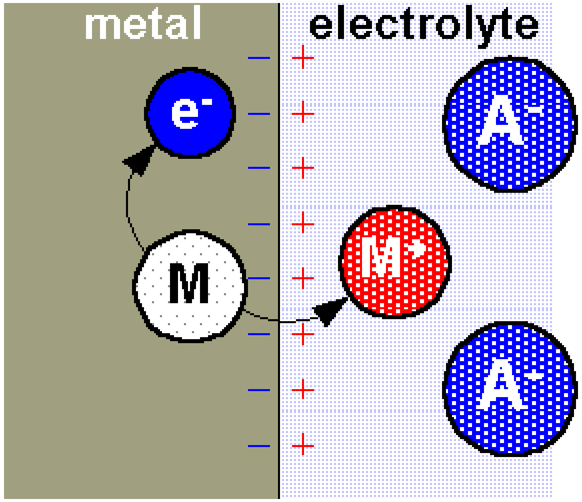
What's going on?

www.vyssotski.ch/BasicsOfInstrumentation/Electrodes.ppt

metal cation

leaving into the electrolyte

No current



One atom M out of the metal is oxidized to form one cation M^+ and giving off one free electron e^- to the metal.

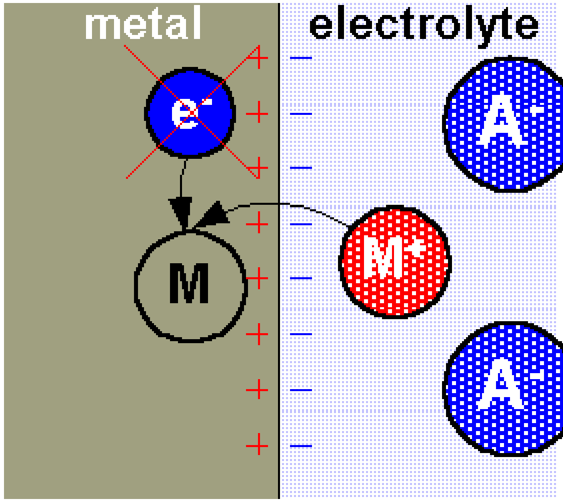
www.vyssotski.ch/BasicsOfInstrumentation/Electrodes.ppt

metal cation

joining the metal

No current

What' s going on?



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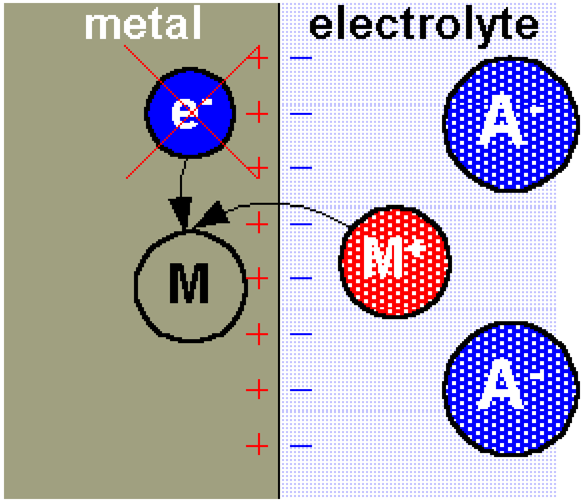
metal cation

joining the metal

No current

One cation M^+
out of the electrolyte
becomes one neutral atom M
taking off one free electron
from the metal.



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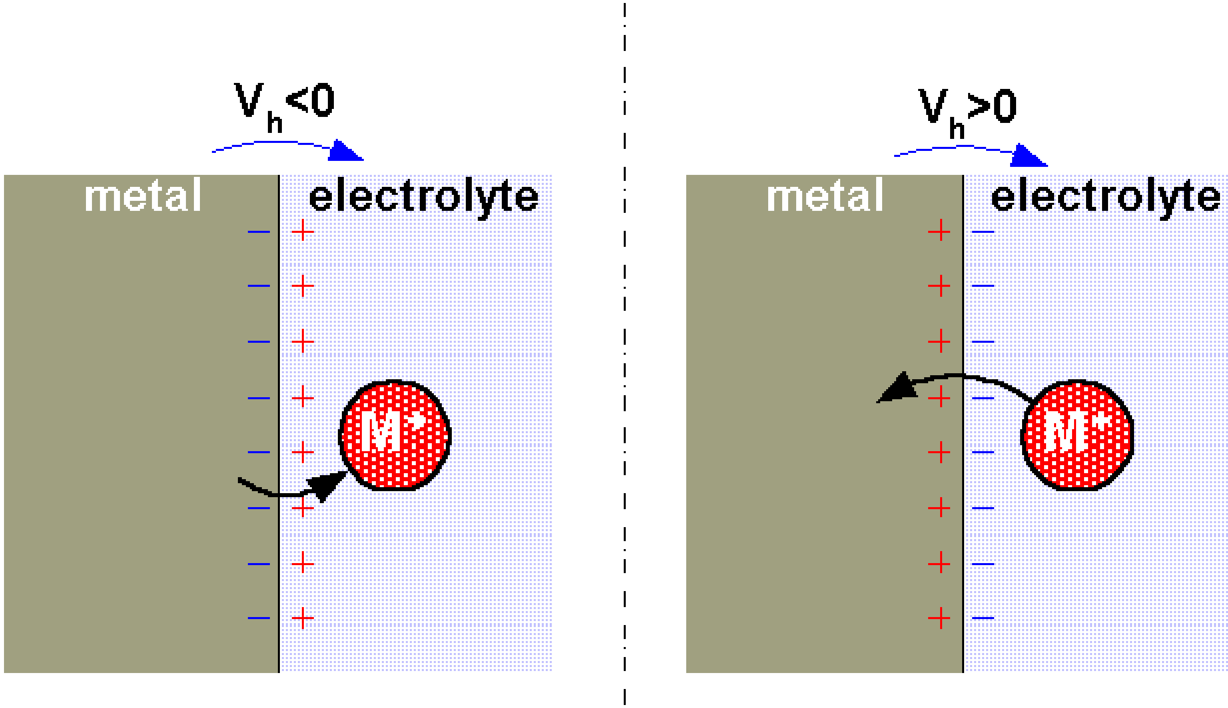
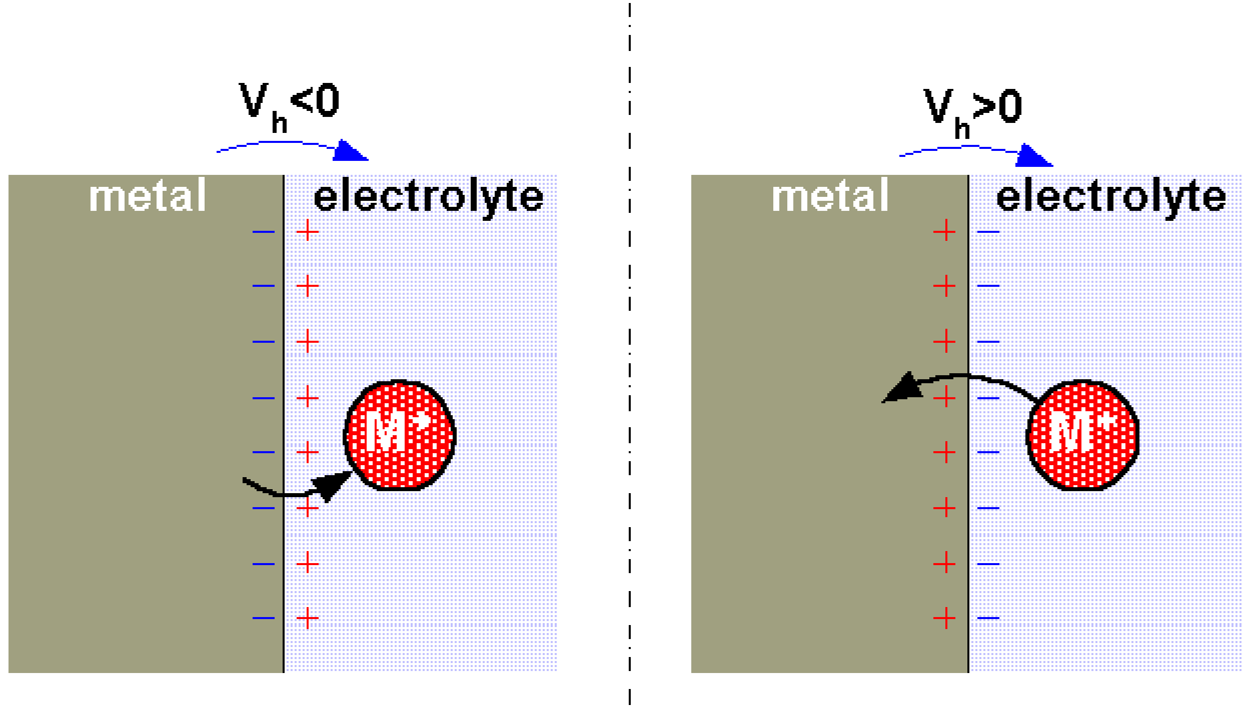
Half-cell voltage



- As reactions reach equilibrium, no current flows between the electrode and the electrolyte. so the rates of oxidation and reduction at the interface are equal.
- Under these conditions, a characteristic potential difference called **equilibrium half-cell potential** is established by the electrode and its surrounding electrolyte which depends on the metal, concentration of ions in solution and temperature (and some second order factors) .

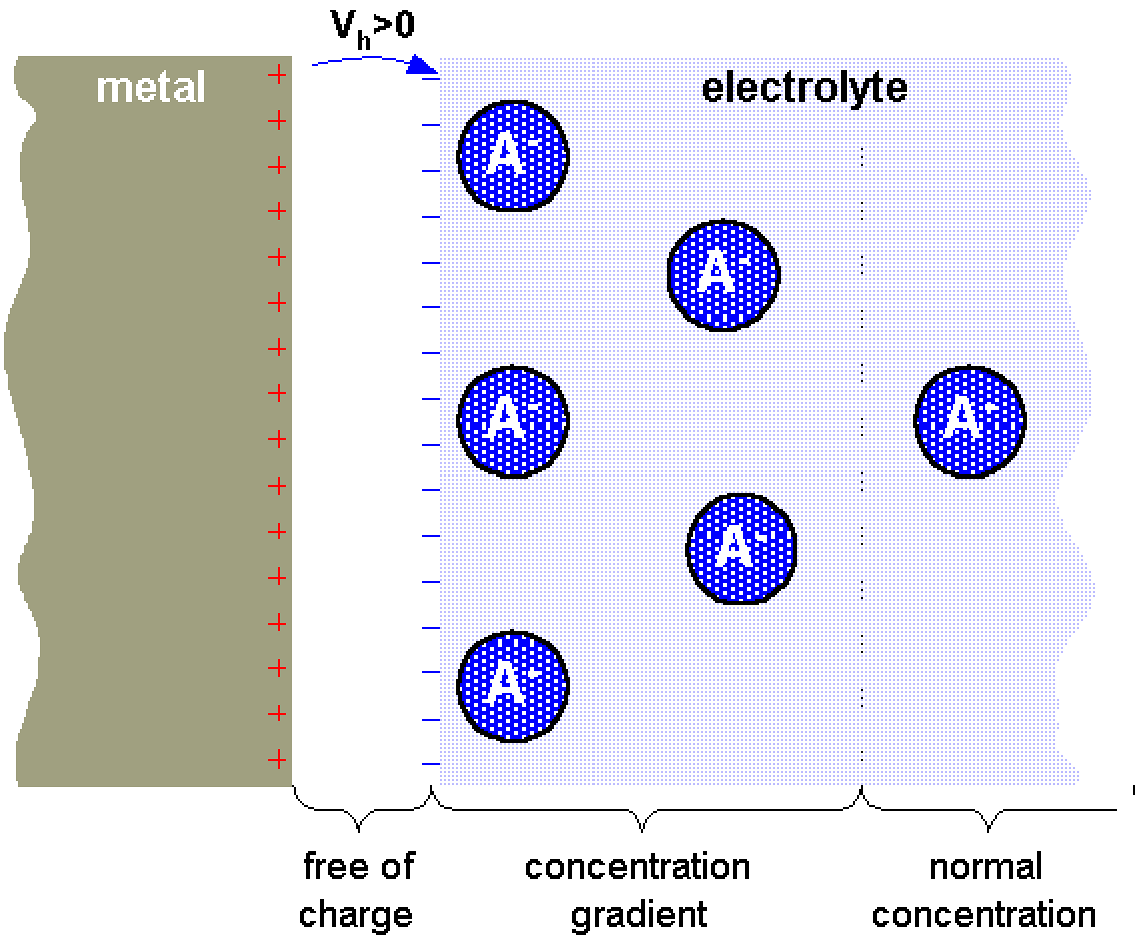
Half-cell voltage



- **Equilibrium half-cell potential** results from the distribution of ionic concentration in the vicinity of the electrode–electrolyte interface.
- Oxidation or reduction reactions at the electrode-electrolyte interface lead to a double-charge layer, similar to that which exists along electrically active biological cell membranes.
- The electrolyte surrounding the metal is at a different electric potential from the rest of the solution.

Electrode double layer

No current



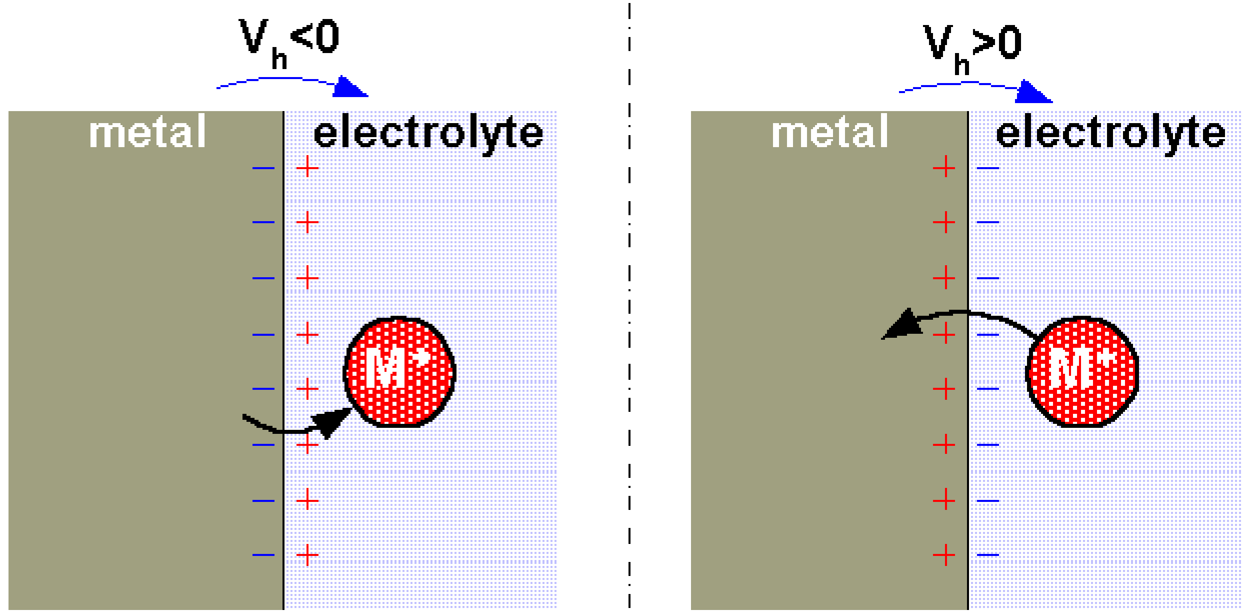
www.vyssotski.ch/BasicsOfInstrumentation/Electrodes.ppt

Half-cell voltage

- Half-cell potential cannot be measured without a second electrode. It is physically impossible to measure the potential of a single electrode: only the difference between the potentials of two electrodes can be measured.
- 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.

No current, 1M salt concentration, T = 25ºC

metal:	Li	Al	Fe	Pb	H	Ag/AgCl	Cu	Ag	Pt	Au
V_h / Volt	*-3,0*	*negativ*			0	*0,223*	*positiv*			*1,68*



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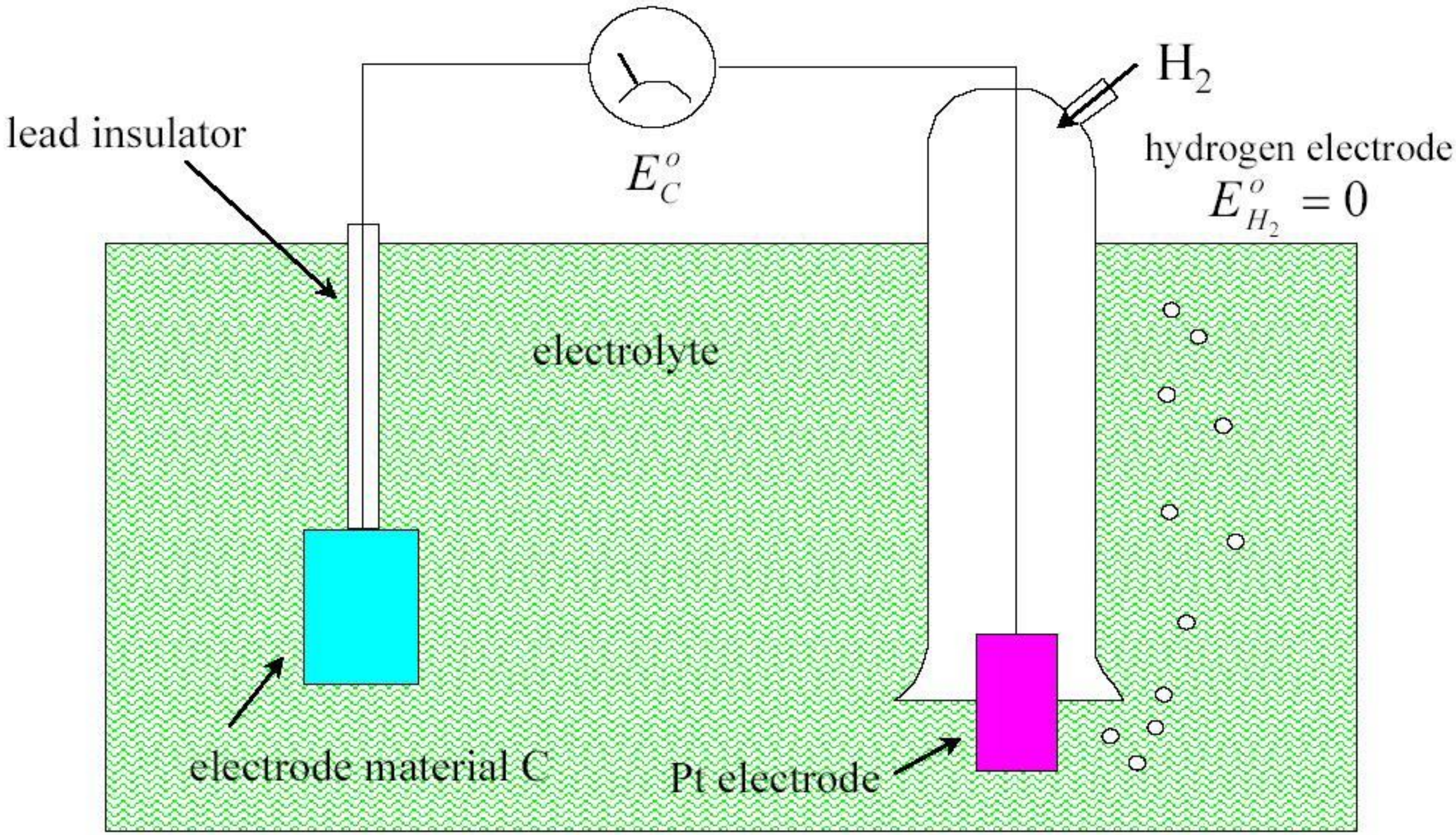
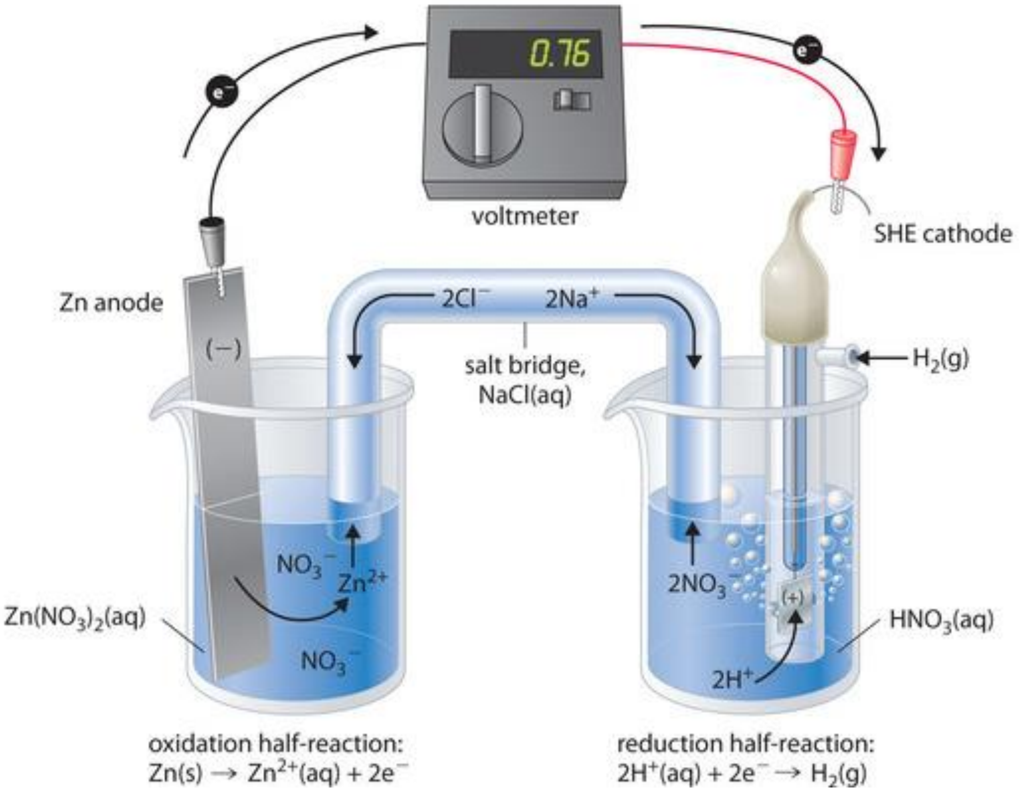
Measuring Half Cell Potential



Note: Electrode material is metal + salt or polymer selective membrane

Half Cell potential

- The standard hydrogen electrode (SHE) is universally used for reference and is assigned a standard potential of 0V.
- The $[H^+]$ in solution is in equilibrium with H_2 gas at a pressure of 1 atm at the Pt-solution interface.
- One especially attractive feature of the SHE is that the Pt metal electrode is not consumed during the reaction.



http://chemwiki.ucdavis.edu/Analytical_Chemistry/Electrochemistry/Standard_Potentials

Half Cell potential

- Cathode

$$2H^+_{(aq)} + 2e^- \rightarrow H_{2(g)} \qquad E^\circ{}_{cathode} = 0V$$

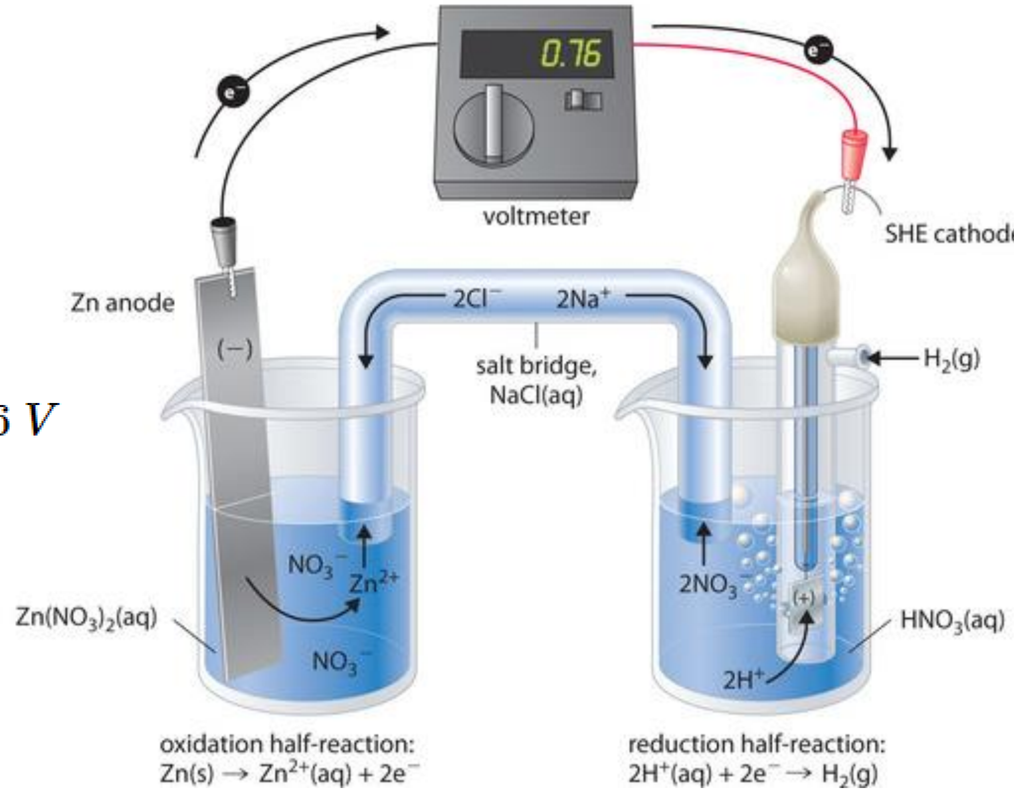
- Anode

$$Zn_{(s)} \rightarrow Zn^{2+}_{(aq)} + 2e^- \qquad E^\circ{}_{anode} = -0.76\ V$$

- Overall

$$Zn_{(s)} + 2H^+_{(aq)} \rightarrow Zn^{2+}_{(aq)} + H_{2(g)}$$

$$E^\circ{}_{cell} = E^\circ{}_{cathode} - E^\circ{}_{anode} = 0.76\ V$$



In figure there is SHE in one beaker and a Zn strip in another beaker containing a solution of Zn^{2+} ions. When the circuit is closed, the voltmeter indicates a potential of 0.76 V. The zinc electrode begins to dissolve to form Zn^{2+} , and H^+ ions are reduced to H_2 in the other compartment. Thus the hydrogen electrode is the cathode, and the zinc electrode is the anode.

http://chemwiki.ucdavis.edu/Analytical_Chemistry/Electrochemistry/Standard_Potentials

Table 5.1 Half-cell Potentials for Common Electrode Materials at 25 °C

The metal undergoing the reaction shown has the sign and potential E^0 when referenced to the hydrogen electrode

Metal and Reaction	Potential E^0 (V)
$Al \rightarrow Al^{3+} + 3e^-$	−1.706
$Zn \rightarrow Zn^{2+} + 2e^-$	−0.763
$Cr \rightarrow Cr^{3+} + 3e^-$	−0.744
$Fe \rightarrow Fe^{2+} + 2e^-$	−0.409
$Cd \rightarrow Cd^{2+} + 2e^-$	−0.401
$Ni \rightarrow Ni^{2+} + 2e^-$	−0.230
$Pb \rightarrow Pb^{2+} + 2e^-$	−0.126
Standard Hydrogen electrode → $H_2 \rightarrow 2H^+ + 2e^-$	0.000 by definition
$Ag + Cl^- \rightarrow AgCl + e^-$	+0.223
$2Hg + 2Cl^- \rightarrow Hg_2Cl_2 + 2e^-$	+0.268
$Cu \rightarrow Cu^{2+} + 2e^-$	+0.340
$Cu \rightarrow Cu^+ + e^-$	+0.522
$Ag \rightarrow Ag^+ + e^-$	+0.799
$Au \rightarrow Au^{3+} + 3e^-$	+1.420
$Au \rightarrow Au^+ + e^-$	+1.680

SOURCE: Data from *Handbook of Chemistry and Physics*, 55th ed., Cleveland, OH: CRC Press, 1974–1975, with permission.

$$H_2 \rightleftarrows 2H \rightleftarrows 2H^+ + 2e^-$$

Some half cell potentials

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!

Polarization

If there is a current between the electrode and electrolyte, the observed half cell potential is often altered due to polarization. The difference is due to polarization of the electrode.

Overpotential
Difference between observed and zero-current half cell potentials

Resistance
Current changes resistance of electrolyte and thus, a voltage drop results.

Concentration
Changes in distribution of ions at the electrode-electrolyte interface

Activation
The activation energy barrier depends on the direction of current and determines kinetics

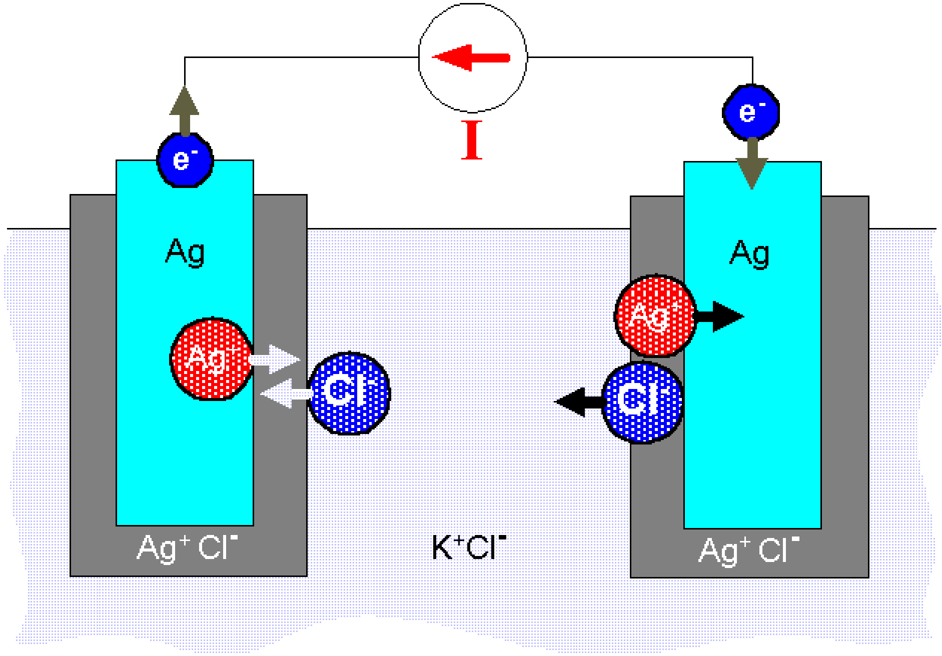
$$V_p = V_R + V_C + V_A + E_0$$

Note: Polarization and impedance of the electrode are two of the most important electrode properties to consider.

Ohmic Overpotential

- Direct result of the resistance of the electrolyte.

- When a current passes between two electrodes immersed in an electrolyte, there is a voltage drop along the path of the current in the electrolyte as a result of its resistance.

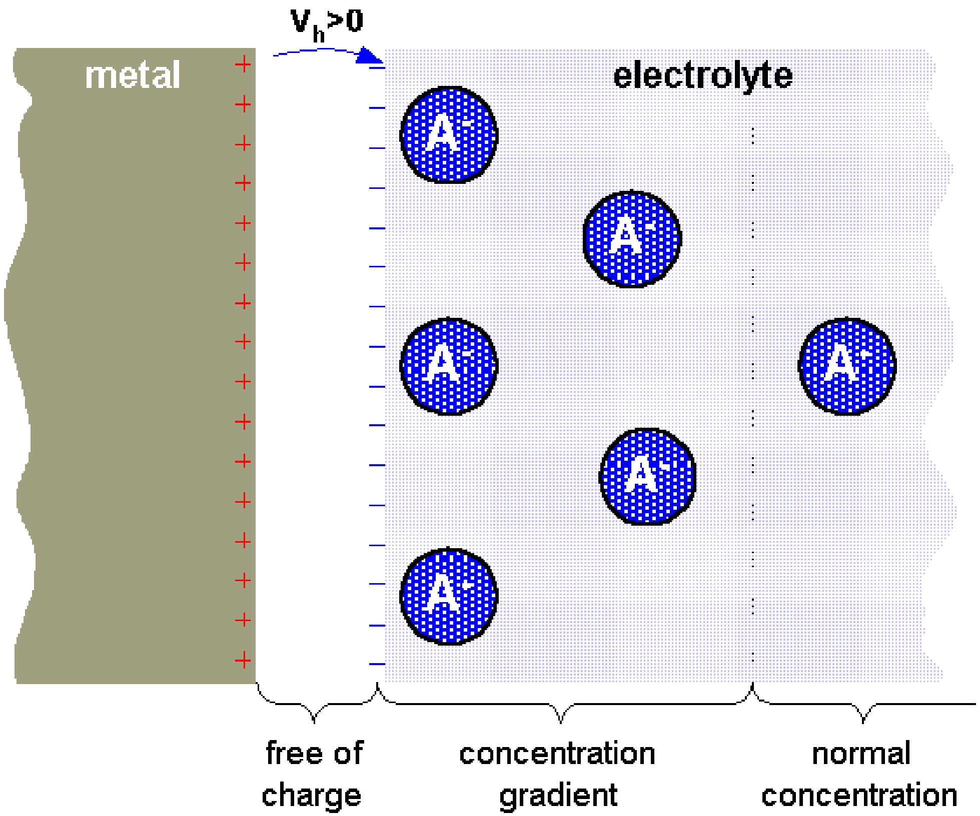


- This drop in voltage is proportional to the current and the resistivity of the electrolyte.

Concentration Overpotential

- Results from changes in the distribution of ions in the electrolyte in the vicinity of the electrode–electrolyte interface.

- When a current is established, the rates of oxidation and reduction at the interface are no longer equal.
- Thus it is reasonable to expect the concentration of ions to change.



- This change results in a different half-cell potential at the electrode. The difference between this and the equilibrium half-cell potential is the concentration overpotential.

Nernst Equation

- When two aqueous ionic solutions of different concentration are separated by an ion-selective semipermeable membrane, an electric potential exists across this membrane.
- Nernst equation

$$E = -\frac{RT}{nF}\ln\frac{a_1}{a_2}$$

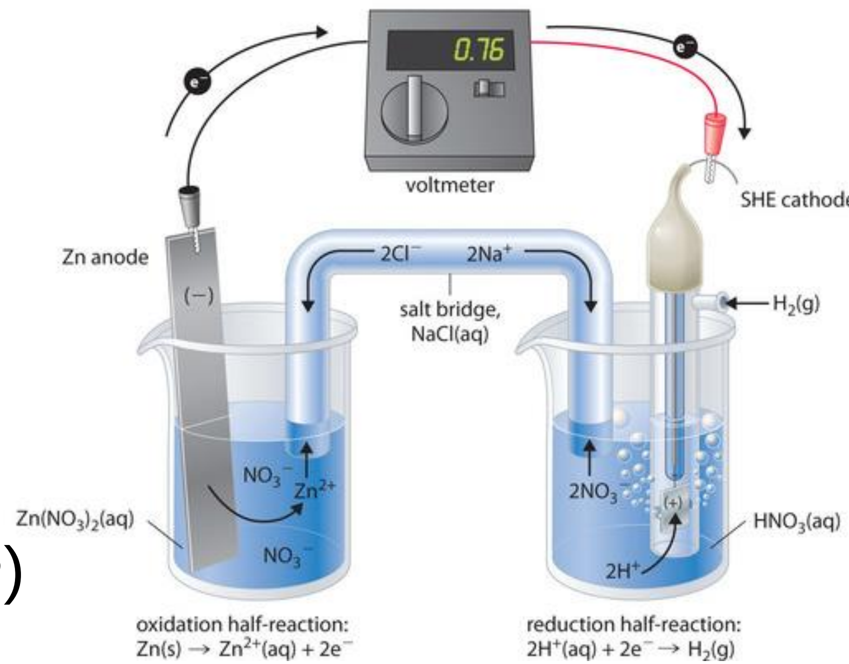
where a_1 and a_2 are the activities of the ions on each side of the membrane.

Half Cell potential

- When the electrode–electrolyte system no longer maintains this standard condition, half-cell potentials different from the standard half-cell potential are observed.
- The differences in potential are determined primarily by temperature
- and ionic activity in the electrolyte

$$E = E^0 + \frac{RT}{nF}\ln(a_{c^{n+}})$$

E = half-cell potential
E^0 = standard half-cell potential
n = valence of electrode material
a_c^{n+} = activity of cation C^{n+}
(*generally same as concentration*)



General Nernst Equation

- The more general form of this equation can be written for a general oxidation–reduction reaction as

$$\alpha A + \beta B \rightleftarrows \gamma C + \delta D + n\mathrm{e}^-$$

where *n* electrons are transferred.

The general Nernst equation for this situation is

$$E = E^0 = \frac{RT}{nF} \ln \frac{a_C^\gamma a_D^\delta}{a_A^\alpha a_B^\beta}$$

where the *a*’s represent the activities of the various constituents of the reaction.

Activation Overpotential

- The charge-transfer processes involved in the oxidation–reduction reaction are not entirely reversible.
- In order for metal atoms to be oxidized to metal ions that are capable of going into solution, the atoms must overcome an energy barrier which governs the kinetics of the reaction.
- The reverse reaction—in which a cation is reduced, thereby plating out an atom of the metal on the electrode—also involves an activation energy, but it does not necessarily have to be the same as that required for the oxidation reaction.
- When there is a current between the electrode and the electrolyte, either oxidation or reduction predominates, and hence the height of the energy barrier depends on the direction of the current.
- This difference in energy appears as a difference in voltage between the electrode and the electrolyte, which is known as the *activation overpotential.*

- Note: for a metal electrode, 2 processes can occur at the electrolyte interfaces:

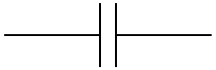
– A capacitive process resulting from the redistribution of charged and polar particles with nocharge-transfer between the solution and the electrode

– A component resulting from the electron exchange between the electrode and a redox species in the solution termed *faradaic process.*

Polarizable and Non-Polarizable Electrodes

Use for recording

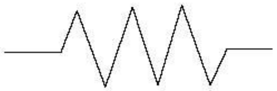
<u>Perfectly Polarizable Electrodes</u>



These are electrodes in which **no 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: Platinum Electrode (Noble metal)

Use for stimulation

<u>Perfectly Non-Polarizable Electrode</u>



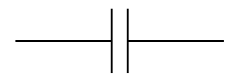
These are electrodes where **current passes freely across the electrode-electrolyte interface**, requiring no energy to make the transition. These electrodes see **no overpotentials**.
Example : Ag/AgCl electrode

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

Polarizable and Non-Polarizable Electrodes

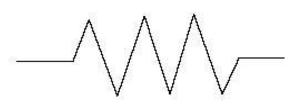
No electrode is perfectly polarizable or non-polarizable.

Platinum electrodes are a reasonable approximation of **perfectly polarizable electrodes.**



- They exhibit Vp that primarily results from Vc and Va.
- Used for stimulation and for higher frequency biopotential measurements.

Ag/AgCl electrodes behave reasonably closely to **perfectly non-polarizable electrodes.**



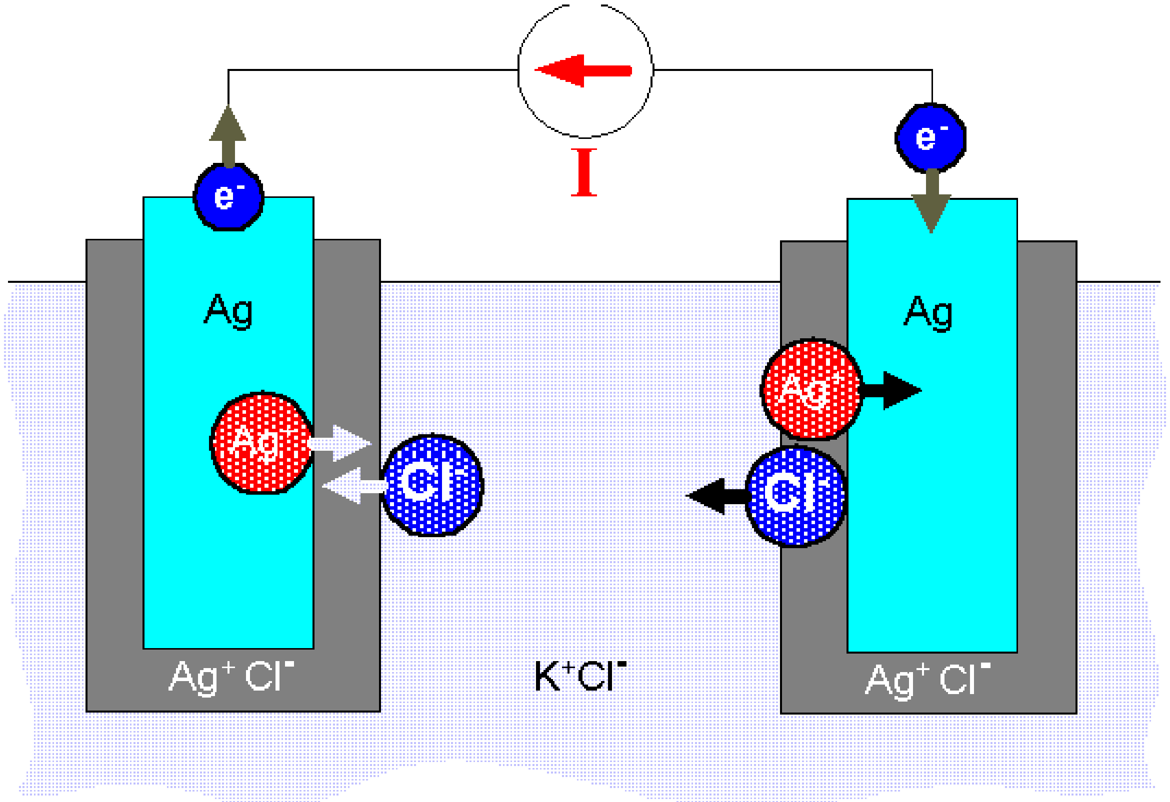
- They exhibit Vp that primarily results from Vr only.
- Used for biopotential recordings that range from high frequency to very low frequency.

Motion artifact

- 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 bio-potential measurements.
- 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.
- **Note:** Motion artifact is minimal for non-polarizable electrodes (Measurement electrodes – AgCl).

silver/silver chloride electrodes

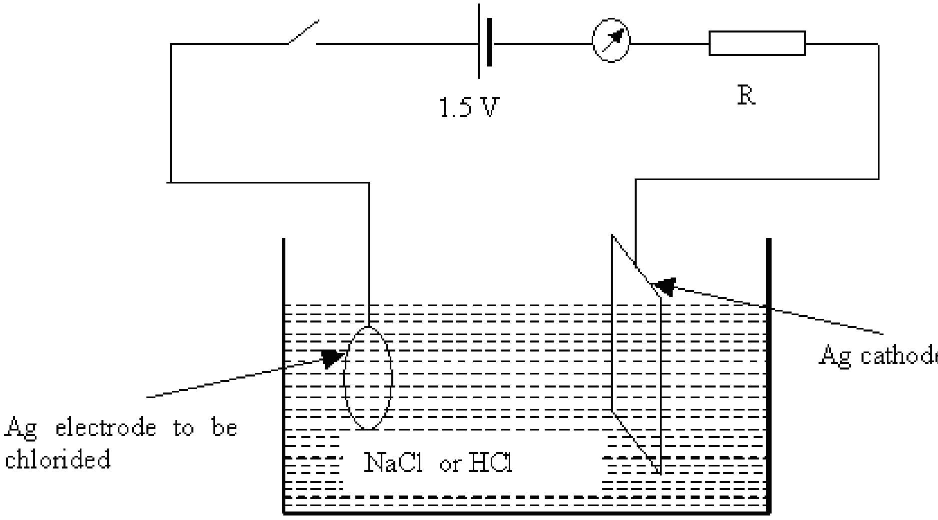
- Ag/AgCl is a practical electrode that approaches the characteristics of a perfectly nonpolarizable electrode
- Can be easily fabricated in the laboratory.



- Consists of a metal coated with a layer of a slightly soluble ionic compound of that metal with a suitable anion.
- Whole structure is immersed in an electrolyte containing the anion in relatively high concentrations.

Electrolytic process - Ag/AgCl electrode fabrication

- An electrochemical cell with the Ag electrode on which the AgCl layer is to be deposited serves as anode and another piece of Ag—having a surface area much greater than that of the anode—serves as cathode.



- The reactions begin to occur as soon as the battery is connected, and the current jumps to its maximal value.
- As the thickness of the deposited AgCl layer increases, the rate of reaction decreases and the current drops.
- This situation continues, and the current approaches zero asymptotically.

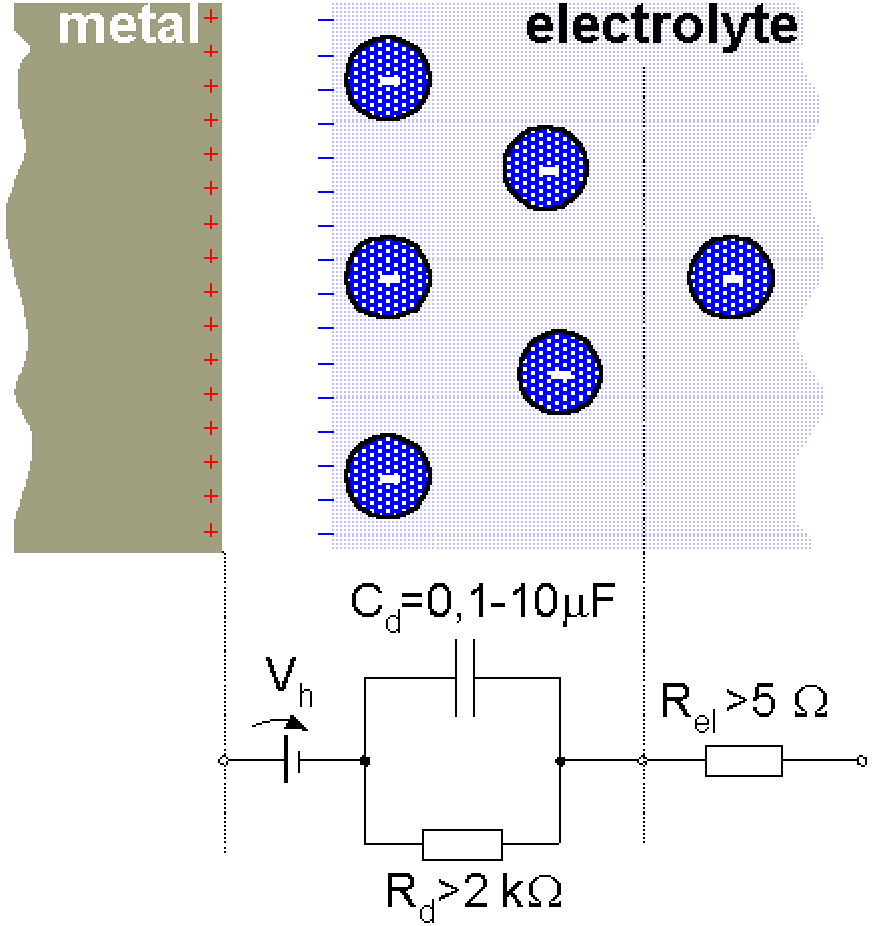
faculty.ksu.edu.sa/ElBrawany/Courses/Med201Files/W7.ppt

Electrode behavior and circuit model

- Current–voltage characteristics of the electrode–electrolyte interface are found to be nonlinear,
- Nonlinear elements are required for modeling electrode behavior.
- Characteristics of an electrode are sensitive to the current passing through the electrode,
- Electrode characteristics at relatively high current densities can be considerably different from those at low current densities.
- Characteristics of electrodes are also waveform-dependent.
- When sinusoidal currents are used to measure the electrode’s circuit behavior, the characteristics are also frequency-dependent.

Electrode behavior and circuit model

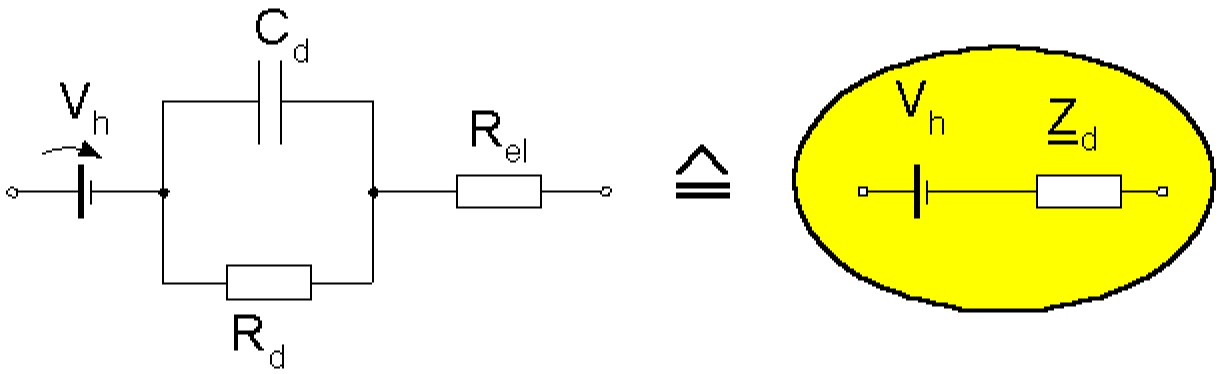
Rel=*R*s is the series resistance associated with interface effects and due to resistance in the electrolyte.



equivalent circuit

equivalent circuit

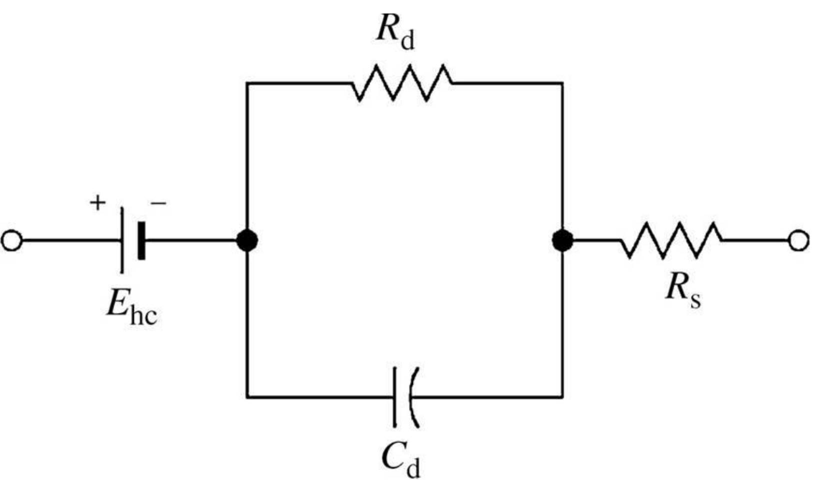
electrode-electrolyte



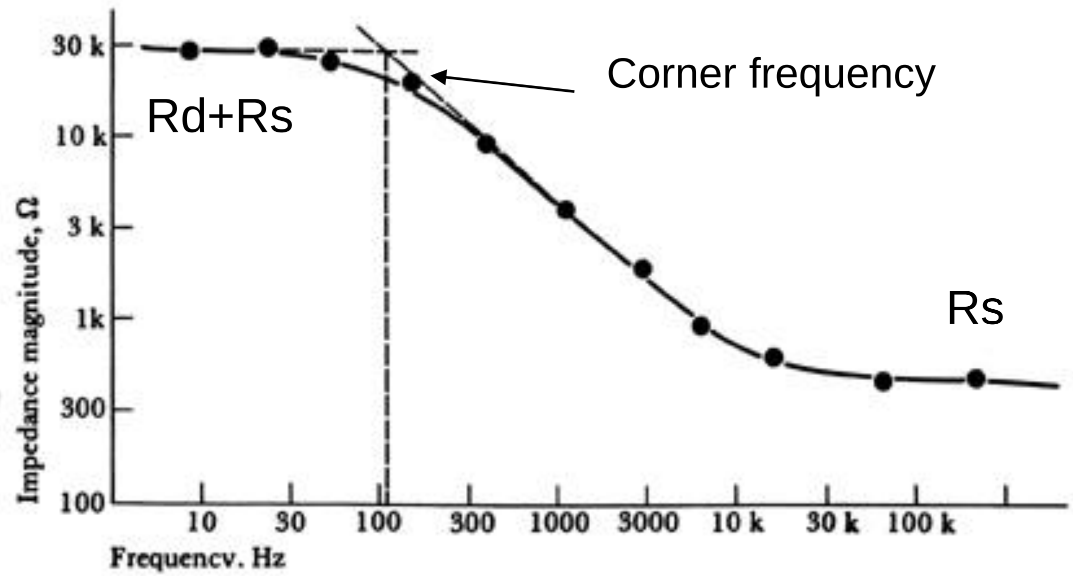
- Circuit values determined by the electrode material and its geometry, and—to a lesser extent—by the material of the electrolyte and its concentration.

Electrode impedance is frequency-dependent

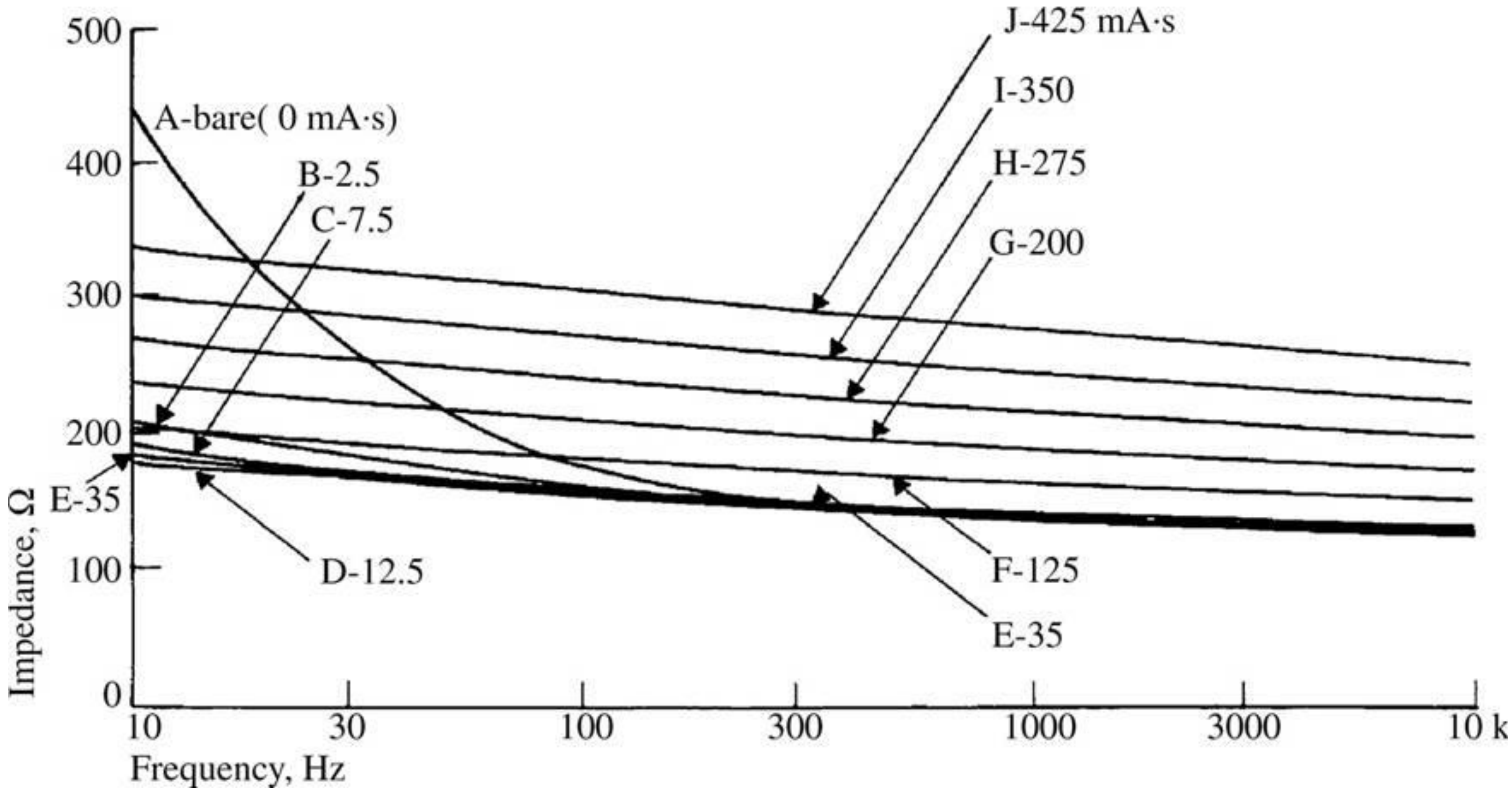
- At high frequencies, where $1/wC \ll R_d$, the impedance is constant at R_s.
- At low frequencies, where $1/wC \gg R_d$, the impedance is again constant but its value is larger, being $R_s + R_d$.
- At frequencies between these extremes, the electrode impedance is frequency-dependent.



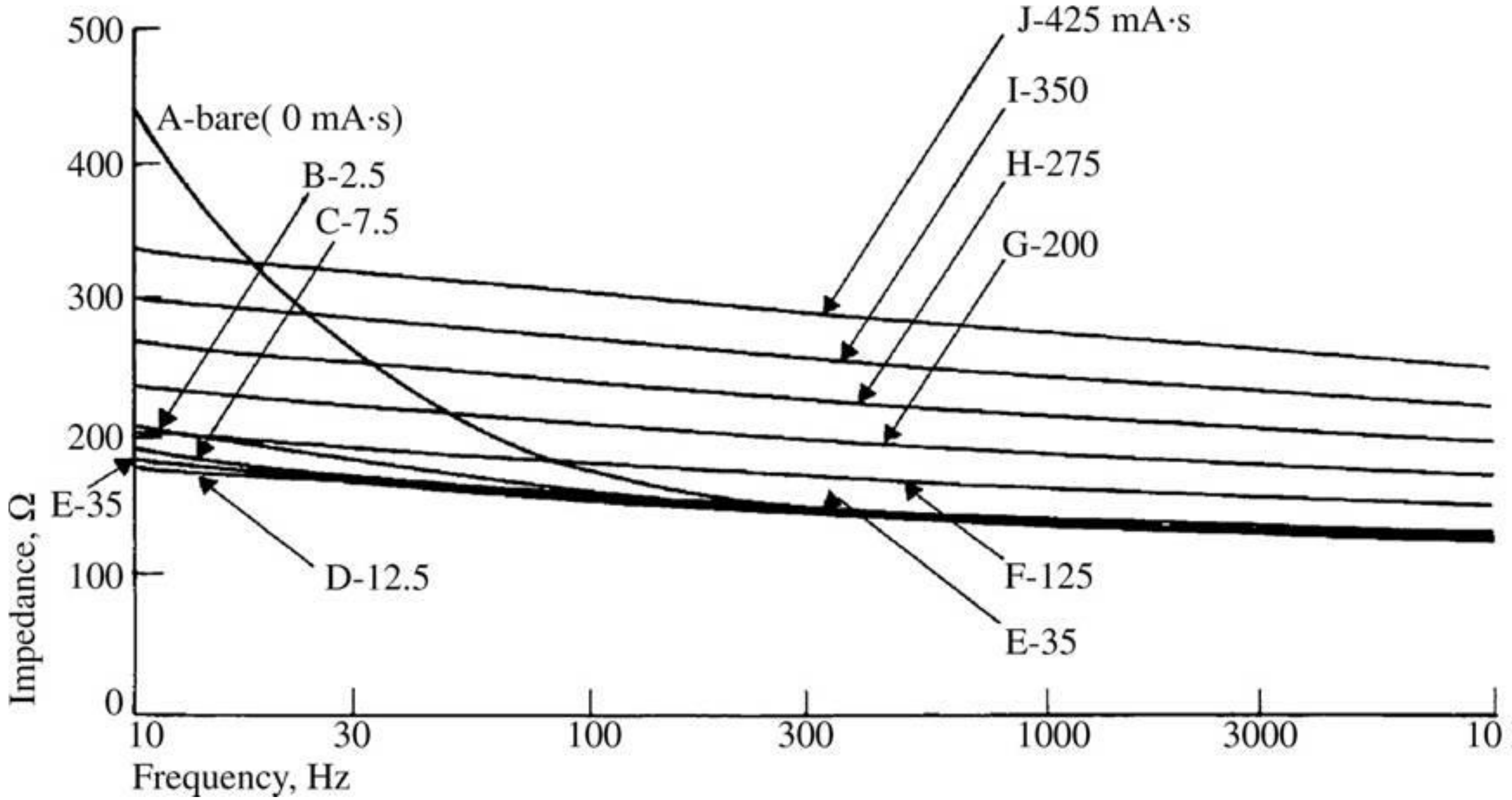
Frequency Response



- For 1 cm^2 at 10 Hz, a nickel- and carbon-loaded silicone rubber electrode has an impedance of approximately 30 kΩ,
- Whereas Ag/AgCl has an impedance of less than 10Ω.



- A metallic silver electrode having a surface area of 0.25 cm^2 had the impedance characteristic shown by curve A.
- Numbers attached to curves indicate number mA.s for each deposit.
- At a frequency of 10 Hz, the magnitude of its impedance was almost three times the value at 300 Hz.
- This indicates a strong capacitive component to the equivalent circuit.



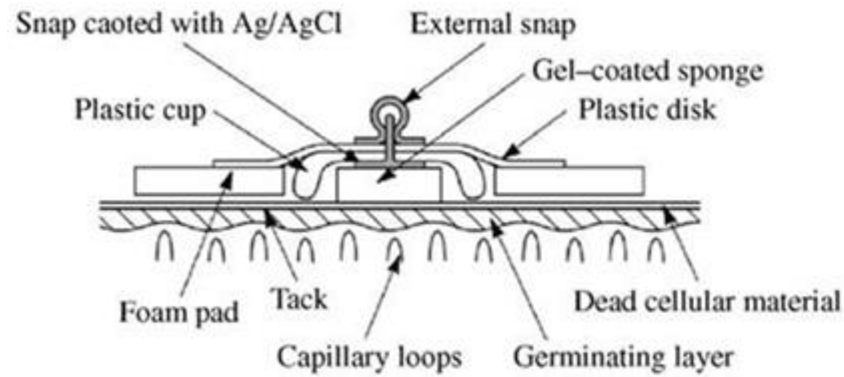
- Electrolytically depositing 2.5 mA·s of AgCl greatly reduced the low-frequency impedance, as reflected in curve B.
- Depositing thicker AgCl layers had minimal effects until the charge deposited exceeded approximately 100 mA·s.
- The curves were then seen to shift to higher impedances in a parallel fashion as the amount of AgCl deposited increased.

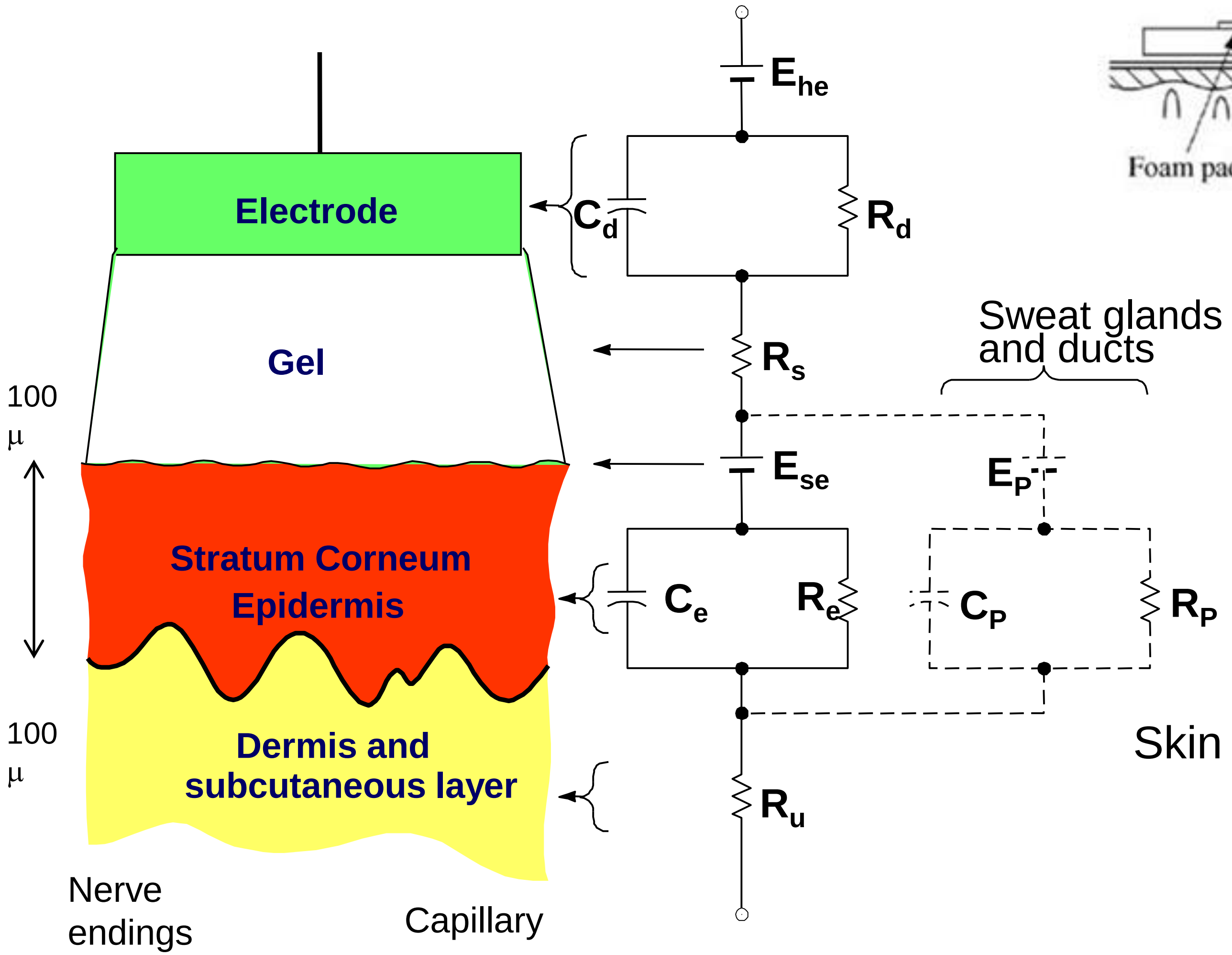
(From L. A. Geddes, L. E. Baker, and A. G. Moore, "Optimum Electrolytic Chloriding of Silver Electrodes," ***Medical and Biological Engineering,*** **1969, 7, pp. 49–56.)**

Electrode-skin interface

- Interface between the electrode–electrolyte and the skin needs to be considered to understand the behavior of the electrodes.
- In coupling an electrode to the skin, we generally use transparent electrolyte gel containing Cl^- as the principal anion to maintain good contact.
- The interface between this gel and the electrode is an electrode–electrolyte interface.
- However, the interface between the electrolyte and the skin is different.

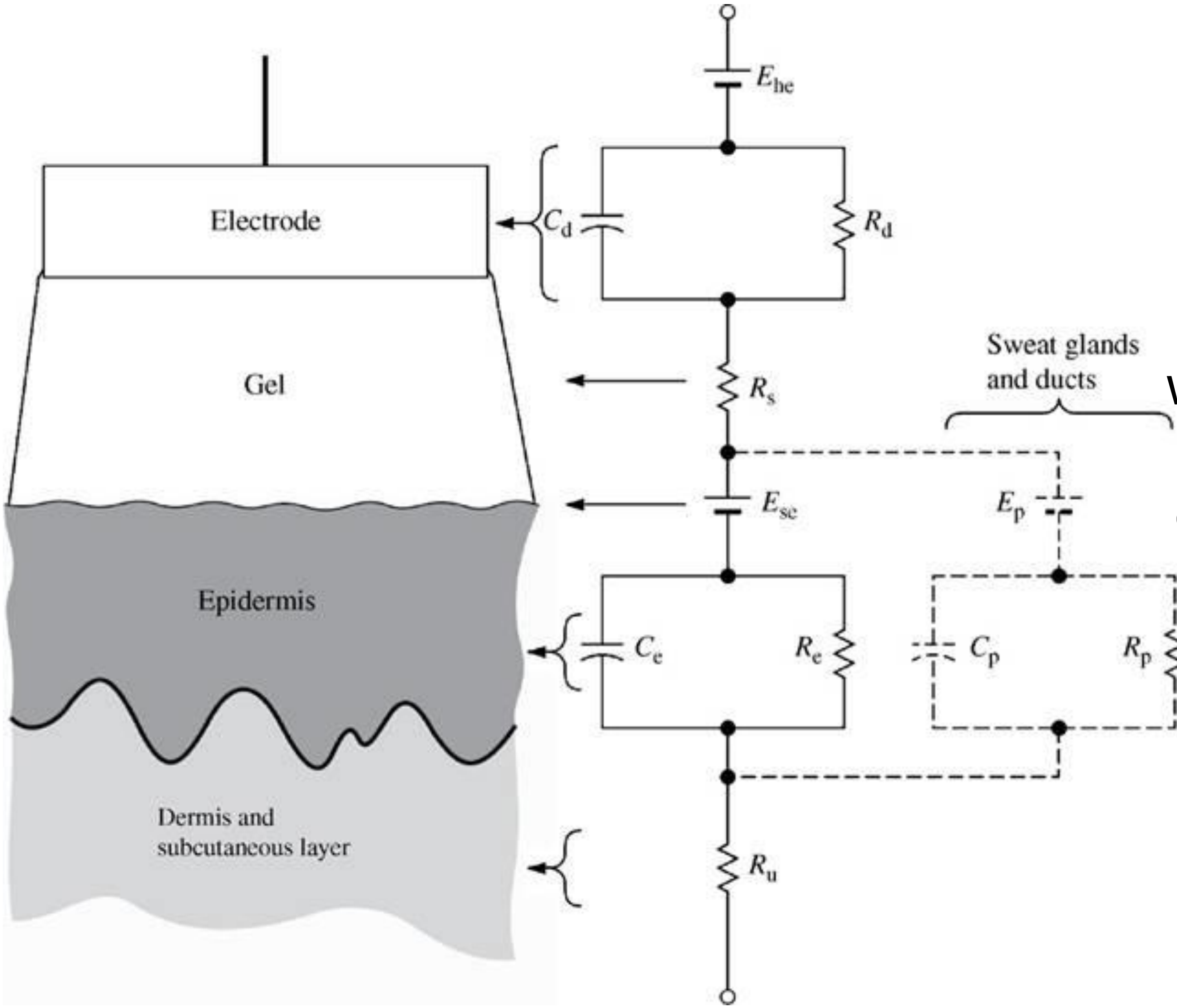
Electrode Skin Interface



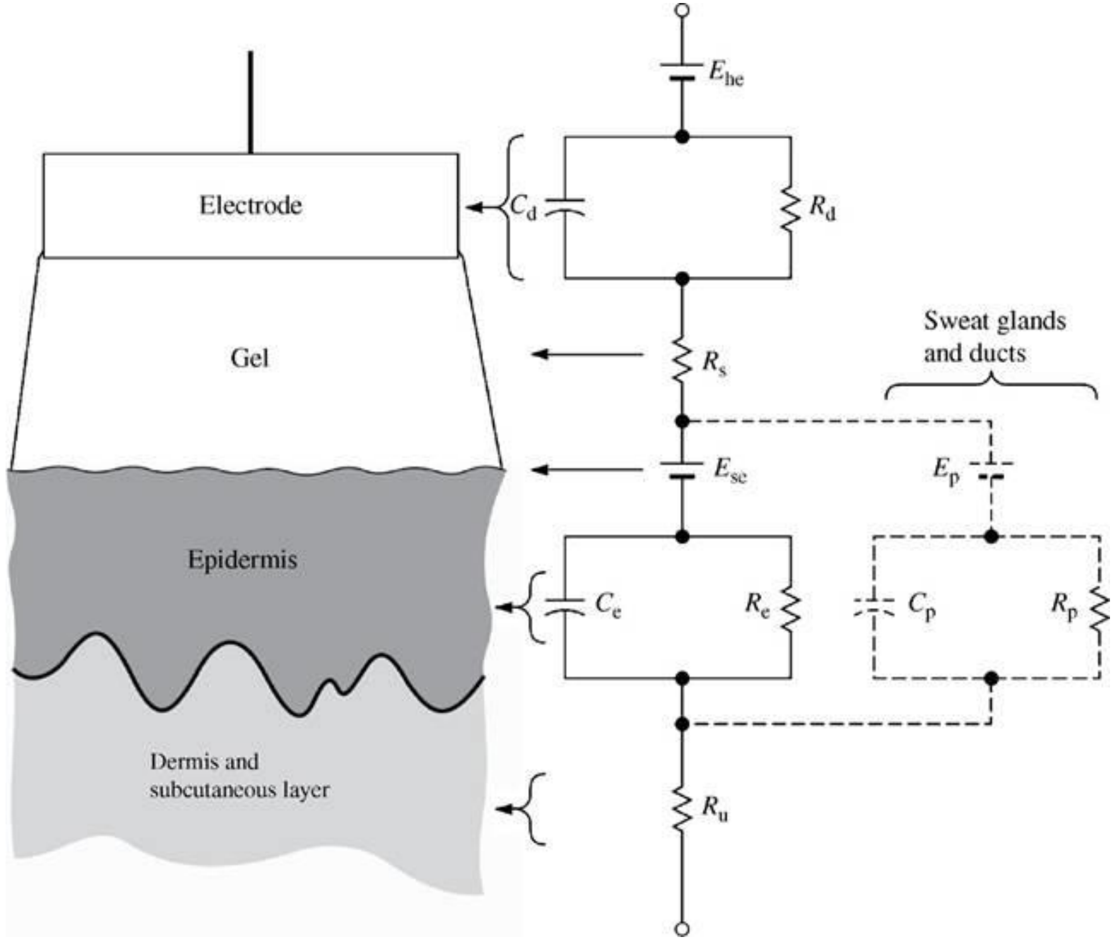


Skin impedance for 1cm^2 patch:
200kΩ @1Hz
200 Ω @ 1MHz

Body-surface electrode is placed against skin, showing the total electrical equivalent circuit



The series resistance R_s is now the effective resistance associated with interface effects of the gel between the electrode and the skin.



- Considering stratum corneum, as a membrane that is semipermeable to ions,
- so if there is a difference in ionic concentration across this membrane,
- there is a potential difference E_{se}, which is given by the Nernst equation.

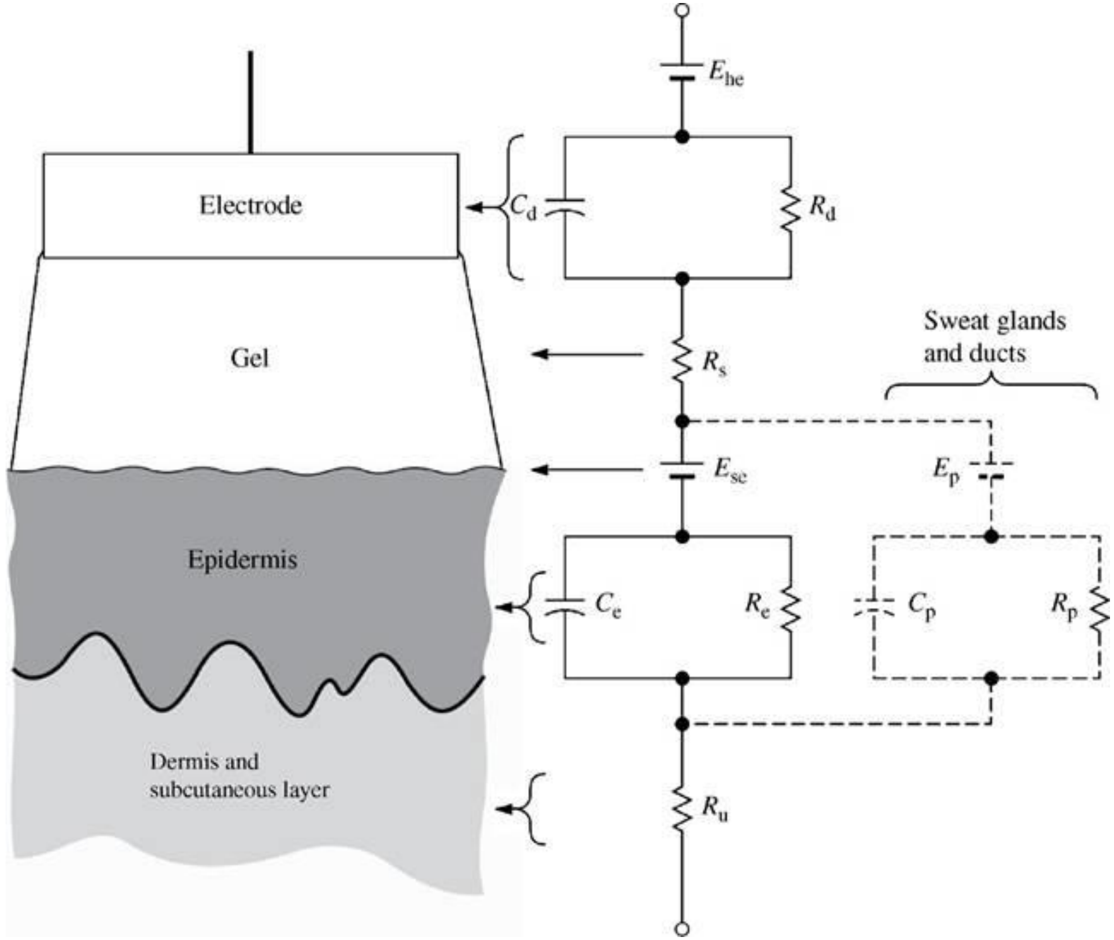
- Epidermal layer has an electric impedance that behaves as a parallel *RC* circuit.
- For 1 cm^2, skin impedance reduces from approximately 200 kΩ at 1 Hz to 200 Ω at 1 MHz.
- The dermis and the subcutaneous layer under it behave in general as pure resistances. They generate negligible dc potentials.

Reducing the effect of stratum corneum

- Minimize the effect of the stratum corneum by removing it, or at least a part of it, from under the electrode.
- Various ways:
  - vigorous rubbing with a pad soaked in acetone
  - abrading the stratum corneum with sandpaper to puncture it.
- This process tends to short out E_{se}, C_e, and R_e
- Improve stability of the signal,
  - but the stratum corneum can regenerate in as short a time as 24 h.

Psychogenic electrodermal responses or galvanic skin reflex (GSR)

- Contribution of the sweat glands and sweat ducts.
- The fluid secreted by sweat glands contains Na^+, K^+, and Cl^- ions, the concentrations of which differ from those in the extracellular fluid.
- There is a potential difference between the lumen of the sweat duct and the dermis and subcutaneous layers.



- There also is a parallel R_pC_p combination in series with this potential that represents the wall of the sweat gland and duct, as shown by the broken lines.

- These components are considered when the electrodes are used to measure the electrodermal response or GSR
- These components are often neglected when we consider biopotential electrodes

What happens when the gel dries?

- Electrolyte gel is used for good contact between electrode and skin during ECG (biopotential) measurements.
- What is the equivalent circuit when the gel is fresh?
- For prolong ambulatory recording, the gel can dry. How would be equivalent circuit change?
- How would be equivalent circuit change if the gel completely dries?
- And how would this affect the ECG recording?

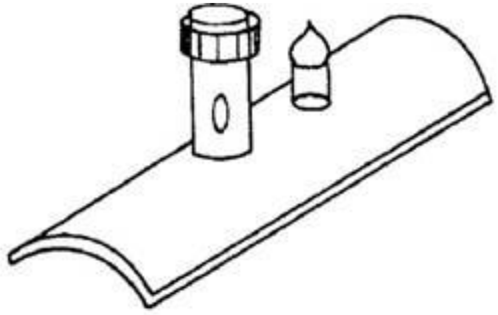
Motion Artifact

- In addition to the half-cell potential E_{hc}, the electrolyte gel–skin potential E_{se} can also cause motion artifact if it varies with movement of the electrode.
- Variations of this potential indeed do represent a major source of motion artifact in Ag/AgCl skin electrodes
- This artifact can be significantly reduced when the stratum corneum is removed by mechanical abrasion with a fine abrasive paper.
- This method also helps to reduce the epidermal component of the skin impedance.
- However, that removal of the body’s outer protective barrier makes that region of skin more susceptible to irritation from the electrolyte gel.
- Stretching the skin changes this skin potential by 5 to 10 mV, and this change appears as motion artifact

Body Surface Electrodes

- The earliest bioelectric potential measurements relied on immersion electrodes that were simply buckets of saline solution into which the patient placed a hand and a foot, as shown in Figure.
- Plate electrodes, first introduced in 1917, were a great improvement on immersion electrodes. They were originally separated from the skin by cotton pads soaked in saline to emulate the immersion electrode mechanism.
- Later, an electrolytic paste was used in place of the pad with the metal in contact with the skin.
- Electrodes that can be placed on the body surface for recording bioelectric signals.
- The integrity of the skin is not compromised.
- Can be used for short or long duration applications

1. **Metal Plate Electrodes**
2. **Suction Electrodes**
3. **Floating Electrodes**
4. **Flexible Electrodes**



(a)

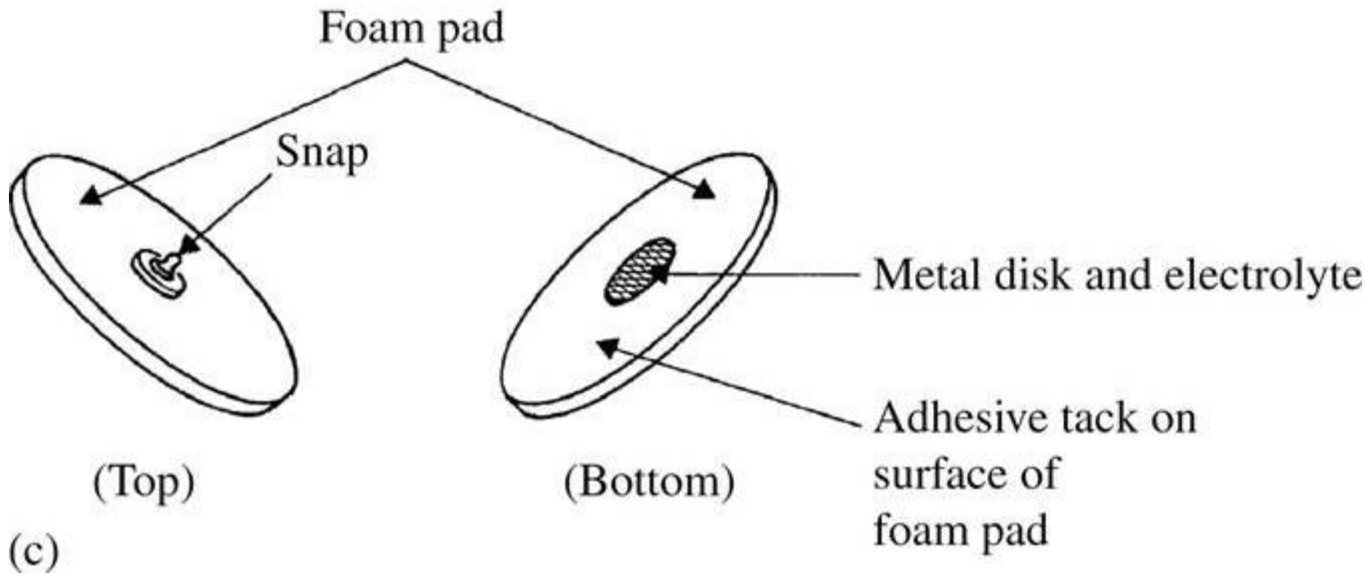
Metal-plate electrode used for application to limbs, traditionally made from German-silver (nickel-silver alloy)

(b)

Metal-disk electrode applied with surgical tape.

- Lead wire soldered or welded on the back surface.
- For ECG application made form disk of Ag with electrolytic deposition of AgCl
- For surface EMG applications made of stainless steel, platinum or gold plated disks to minimize electrolyte chemical reaction.
- Acts as polarizable electrode, and prone to motion artifacts

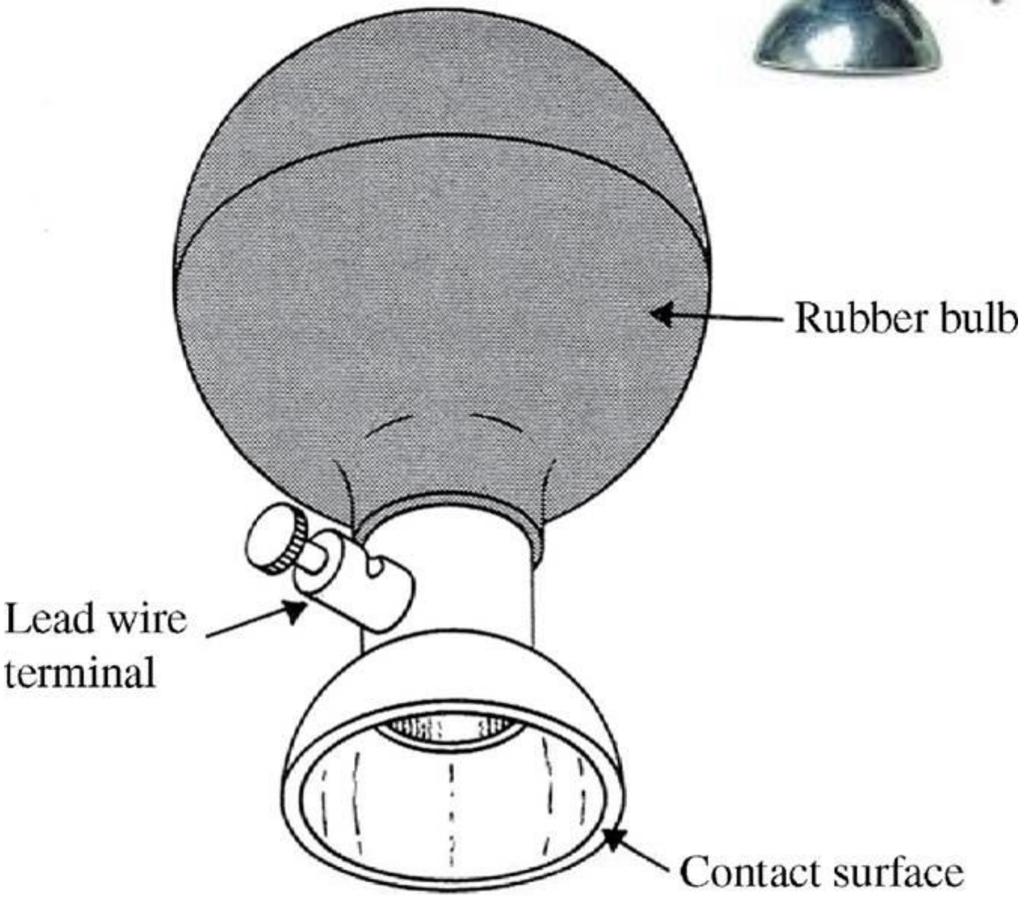
Disposable foam-pad electrodes, often used with ECG monitoring apparatus



- Relatively large disk of plastic foam with silver-plated disk serving as electrode, coated with AgCl
- Layer of electrolyte gel covers the disk
- Electrode side of foam covered with adhesive material
- They are preffered in hospitals due to being easy to apply and disposable.

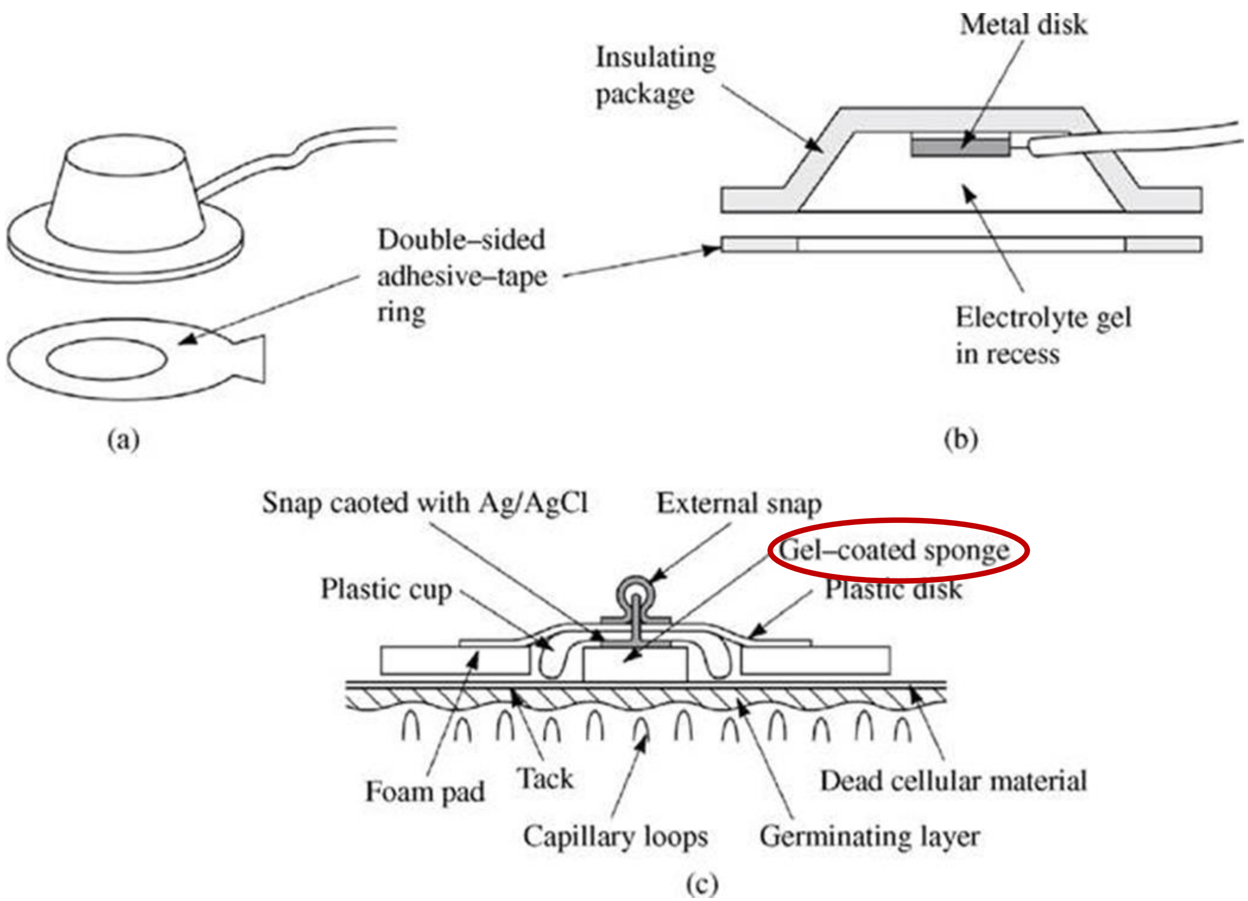
Metallic suction electrode

- A metallic suction electrode is often used as a precordial (chest) electrode on clinical electrocardiographs.
- It requires no straps or adhesives for holding it in place.
- Electrolyte gel is placed on the contacting surface of electrode.
- This electrode can be used only for short periods of time.



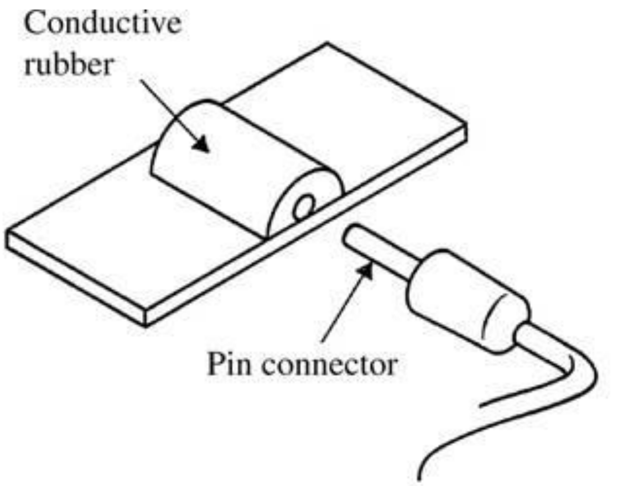
Floating Electrodes

- Mechanical technique to reduce noise. Isolates the electrode-electrolyte interface from motion artifacts.
- Metal disk (actual electrode) is recessed.
- Floating in the electrolyte gel.
- Not directly contact with the skin.
- Reduces motion artifacts.



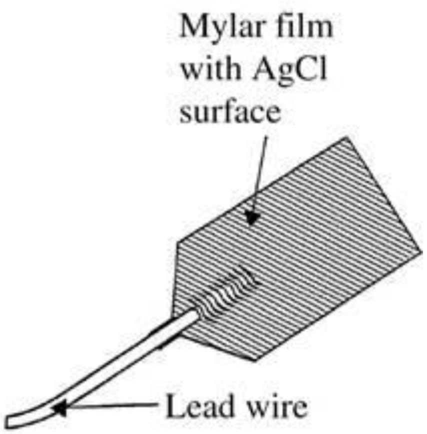
Flexible body-surface electrodes (a) Carbon-filled silicone rubber electrode

- Solid electrodes cannot conform to body-surface topology resulting additional motion artifacts.
- Carbon particles filled in the silicone rubber compound (conductive) in the form of a thin strip or disk is used as the active element of an electrode.
- A pin connector is pushed into the lead connector hole and electrode is usd like a metal plate electrode.
- Applications – monitoring premature infants (2500gr) who are not suitable for using standard electrodes.

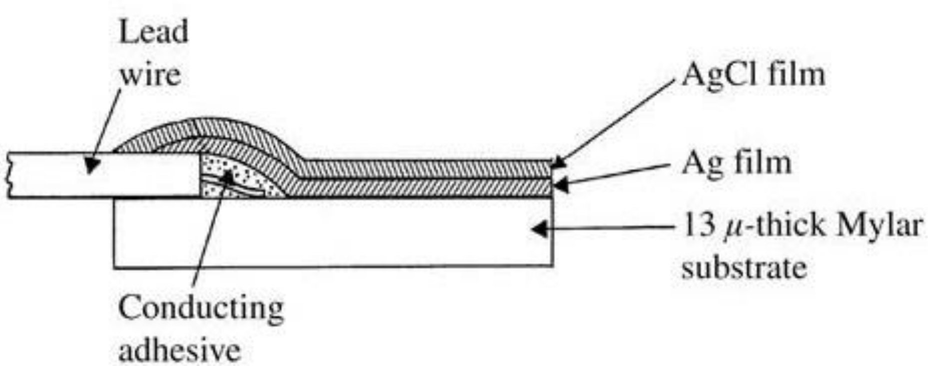


Flexible thin-film neonatal electrode (after Neuman, 1973). (c) Cross-sectional view of the thin-film electrode in (b)

- The basic electrode consists of 13 μm-thick Mylar film with Ag/AgCl film deposition.
- Lead wire is sticked to this film with an adhesive.
- Have the advantage of being flexible and conforming to the shape of newborn's chest.
- No need to be removed as they are X-ray transparent
- Monitoring new-born infants
- Drawback – High electric imped



(b)

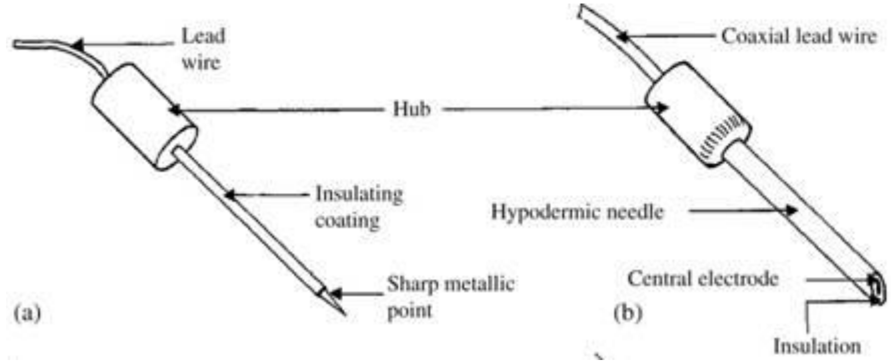


(c)

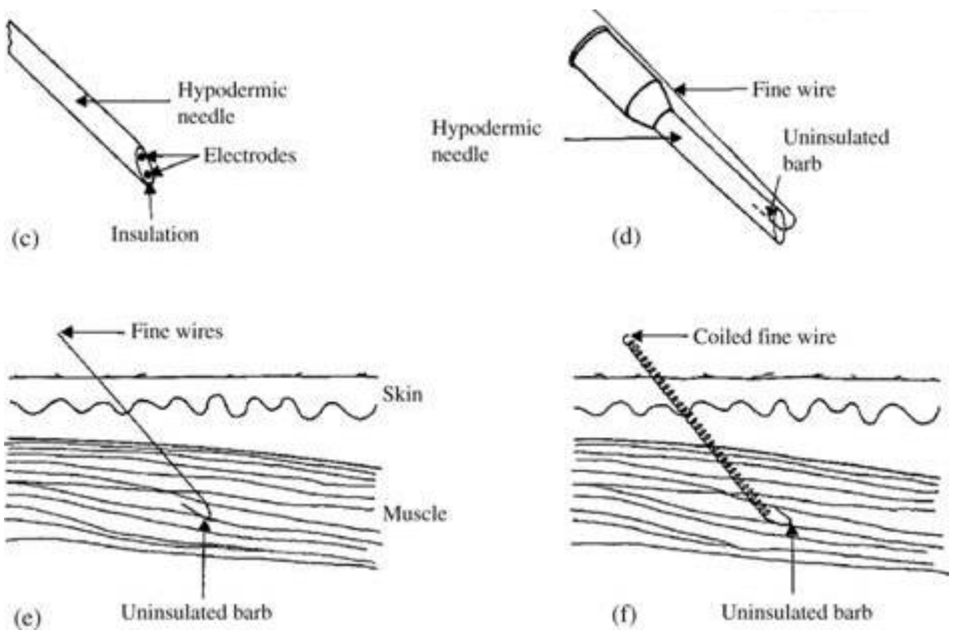
Internal Electrodes – detect biopotential within body

- *Percutaneous electrodes* - electrode itself or the lead wire crosses the skin,
- Entirely *internal electrodes* - connection is to an implanted electronic circuit such as a radiotelemetry transmitter.
- No limitation due to electrolyte-skin interface
- Electrode behaves in the way dictated entirely by the electrode–electrolyte interface.
- No electrolyte gel is required to maintain this interface, because extracellular fluid is present.

(a) Insulated needle electrode, (b) Coaxial needle electrode

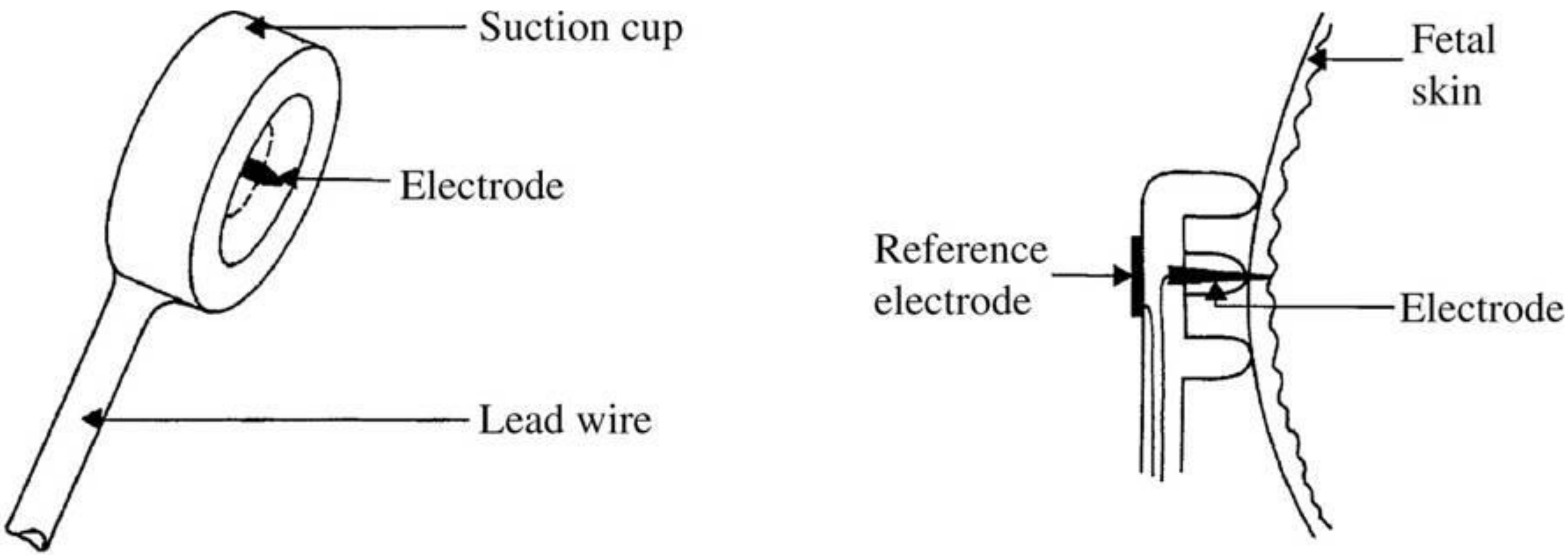


(c) Multiple electrodes in a single needle - Bipolar coaxial electrode,



Chronic recordings using percutaneous wire electrodes - (d) Fine-wire electrode connected to hypodermic needle, before being inserted, (e) Cross-sectional view of skin and muscle, showing fine-wire electrode in place, (f) Cross-sectional view of skin and muscle, showing coiled fine-wire electrode in place.

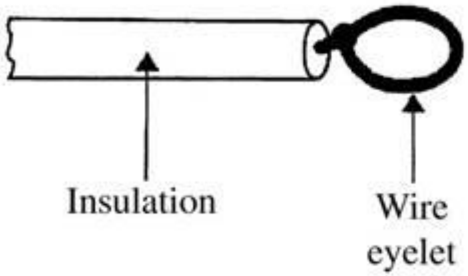
Electrodes for detecting fetal electrocardiogram during labor, by means of intracutaneous needles (a) Suction electrode, (b) Cross-sectional view of suction electrode in place, showing penetration of probe through epidermis,



(a) (b)

(c)

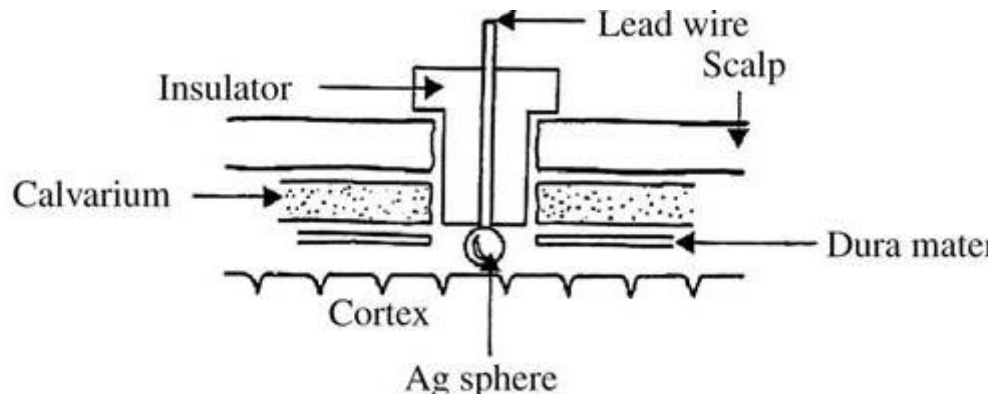
(c) Helical electrode, that is attached to fetal skin by corkscrew-type action.



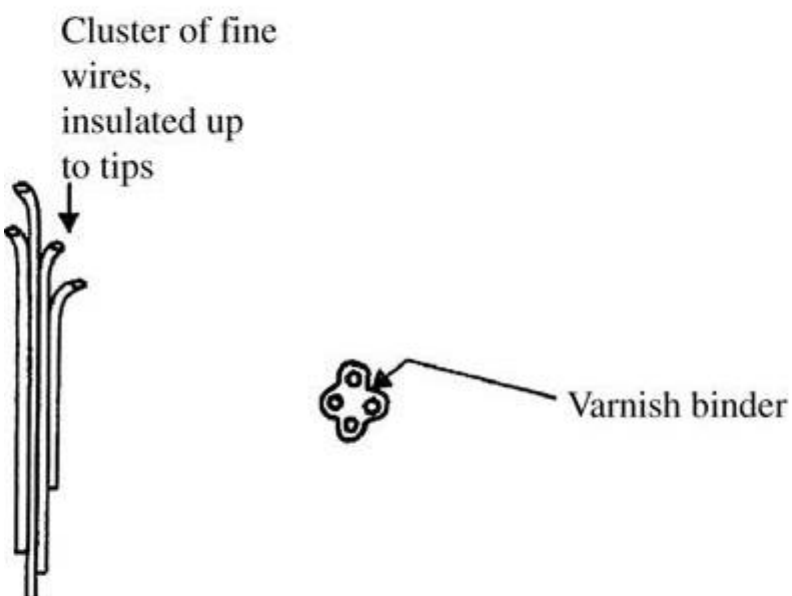
(a)

Insulated multistranded stainless steel or platinum wire wire-loop electrode for implantable wireless transmission electrodes for detecting biopotentials

(b) platinum-sphere cortical-surface potential electrode



(b)



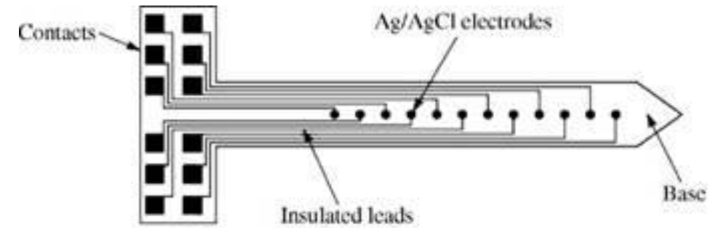
(c)

(c) Multielement depth electrode for deep cortical potential measurement from multiple points.

Electrode Arrays

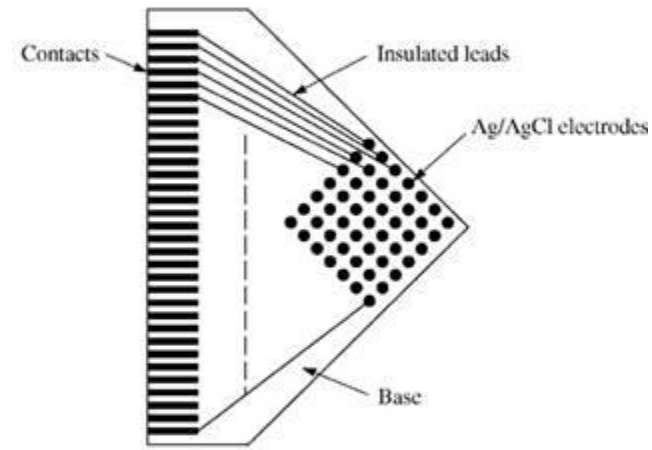
- Implantable electrode arrays can be fabricated one at a time using clusters of fine insulated wires, this technique is both time-consuming and expensive.
- When such clusters are made individually, each one will be somewhat different from the other.
- To minimize these problems is to utilize microfabrication technology to fabricate identical 2- and 3-D electrode arrays.

Examples of microfabricated electrode arrays,



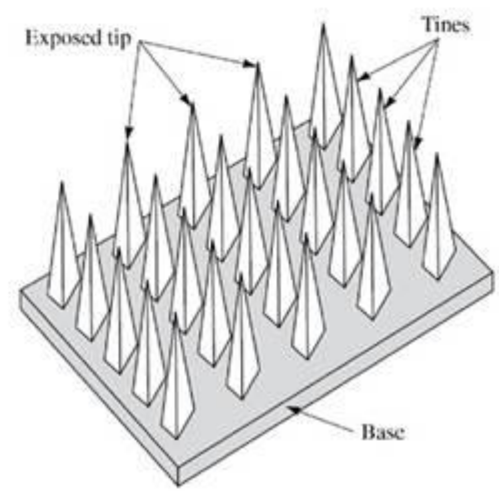
(a)

(a) One-dimensional plunge electrode array (after Mastrototaro *et al.*, 1992), -- measuring transmural potential distributions in beating myocardium



(b)

(b) Two-dimensional array – extracellular recording of neural signals in animal studies



(c)

(c) Three-dimensional array (after Campbell *et al.*, 1991). – cardiac ECG mapping

Microelectrodes

Why

Measure potential difference across cell membrane

Requirements

- Small enough to be placed into cell
- Strong enough to penetrate cell membrane
- Typical tip diameter: 0.05 – 10 microns

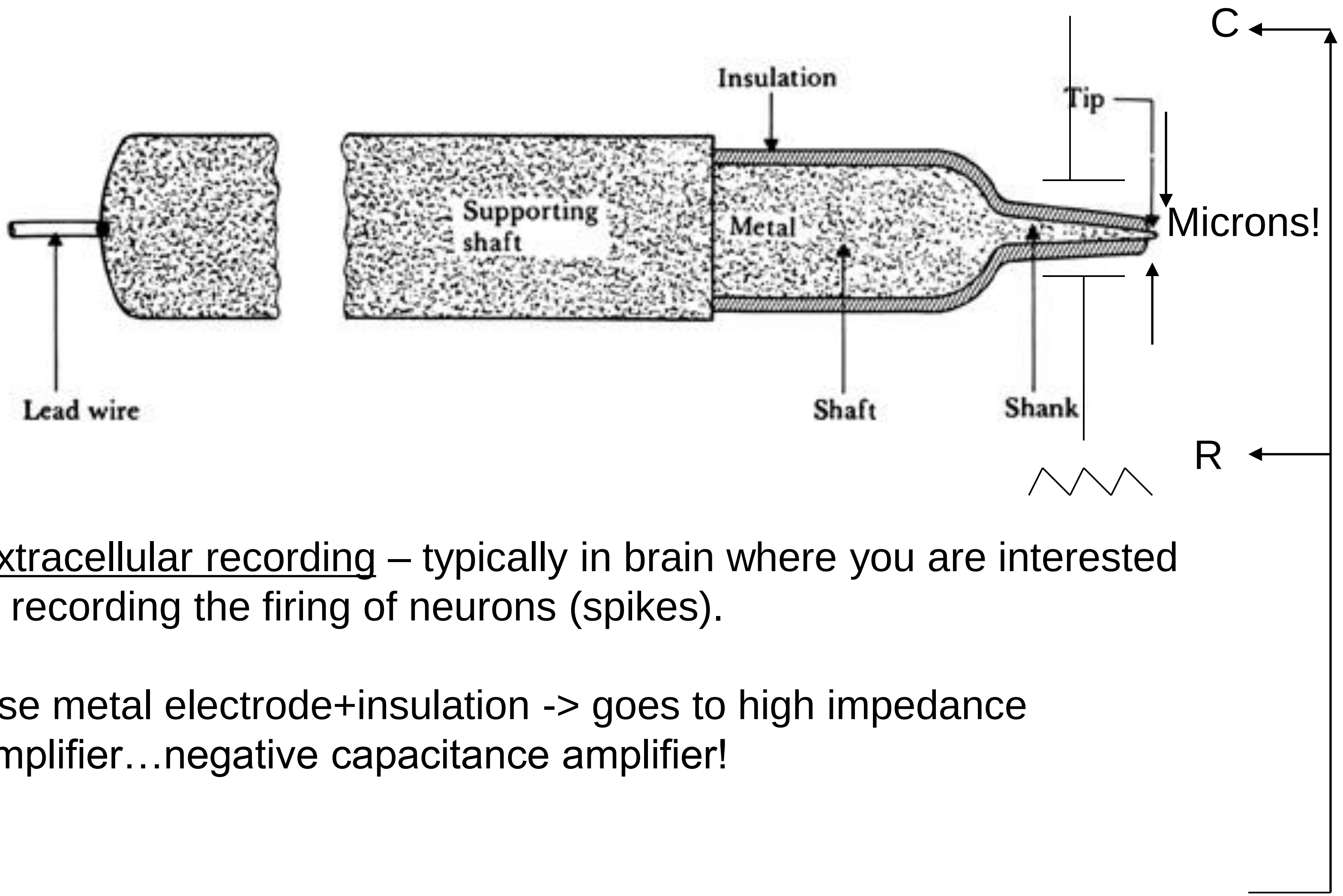
Intracellular

Extracellular

Types

- Solid metal -> Tungsten microelectrodes
- Supported metal (metal contained within/outside glass needle)
- Glass micropipette -> with Ag-AgCl electrode metal

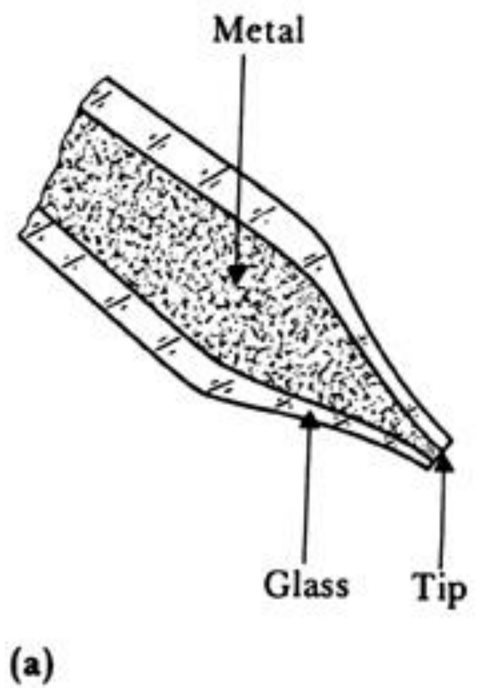
Metal Microelectrodes

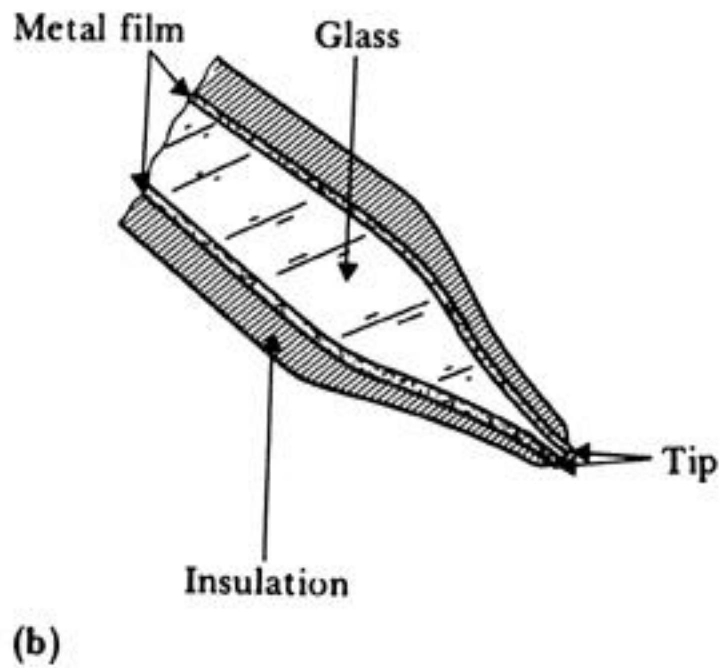


<u>Extracellular recording</u> – typically in brain where you are interested in recording the firing of neurons (spikes).

Use metal electrode+insulation -> goes to high impedance amplifier…negative capacitance amplifier!

Metal Supported Microelectrodes





(a) Metal inside glass

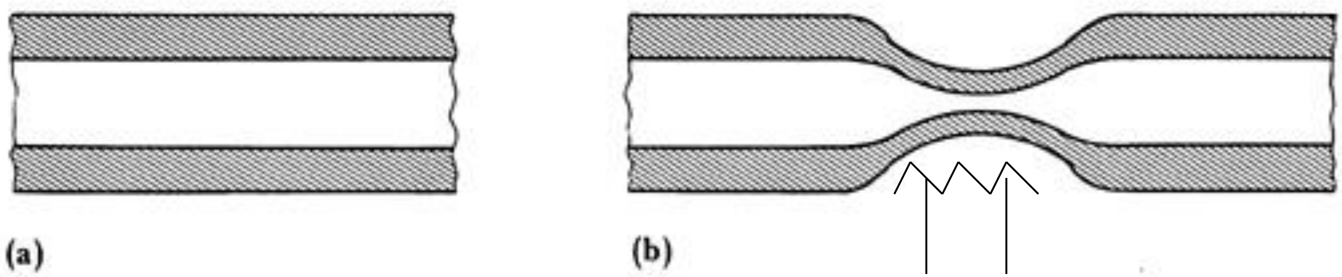
(b) Glass inside metal

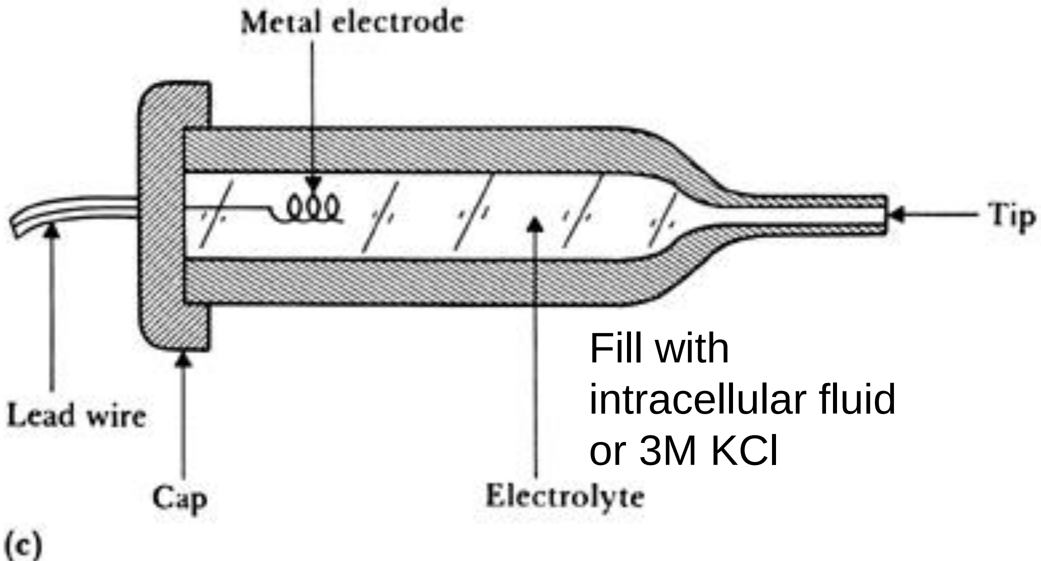
Glass Micropipette

Ag-AgCl wire+3M KCl has very low junction potential and hence very accurate for dc measurements (e.g. action potential)

heat

pull





Fill with intracellular fluid or 3M KCl

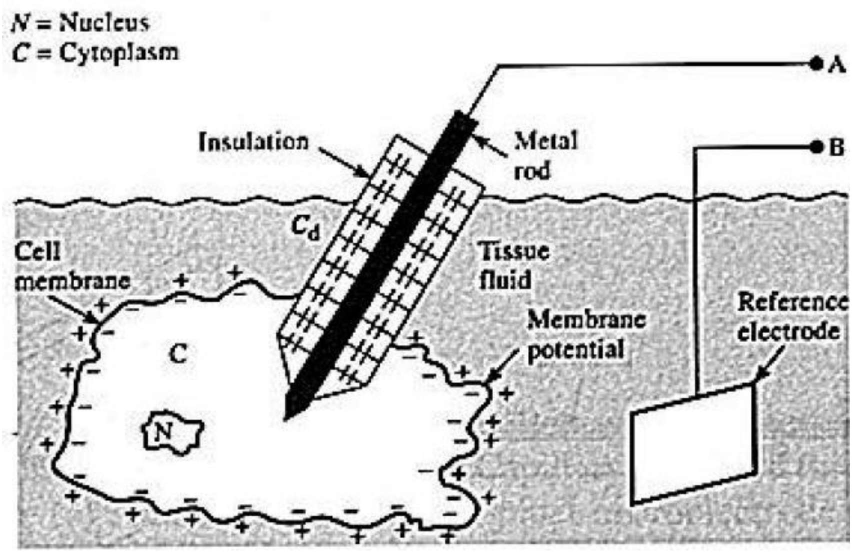
A glass micropipet electrode filled with an electrolytic solution
(a) Section of fine-bore glass capillary.
(b) Capillary narrowed through heating and stretching.
(c) Final structure of glass-pipet microelectrode.

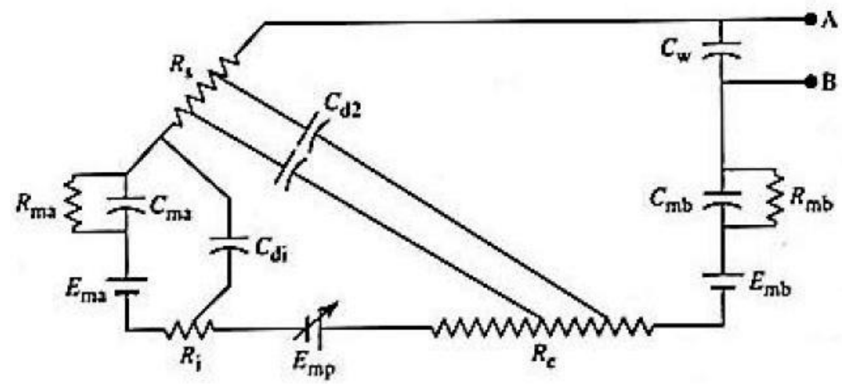
<u>Intracellular recording</u> – typically for recording from cells, such as cardiac myocyte

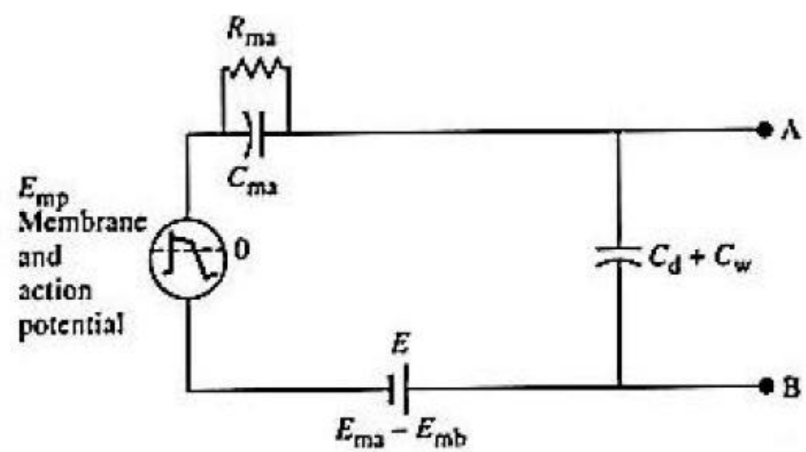
<u>Need high impedance amplifier…negative capacitance amplifier</u>!

Electrical Properties of Microelectrodes

Metal Microelectrode







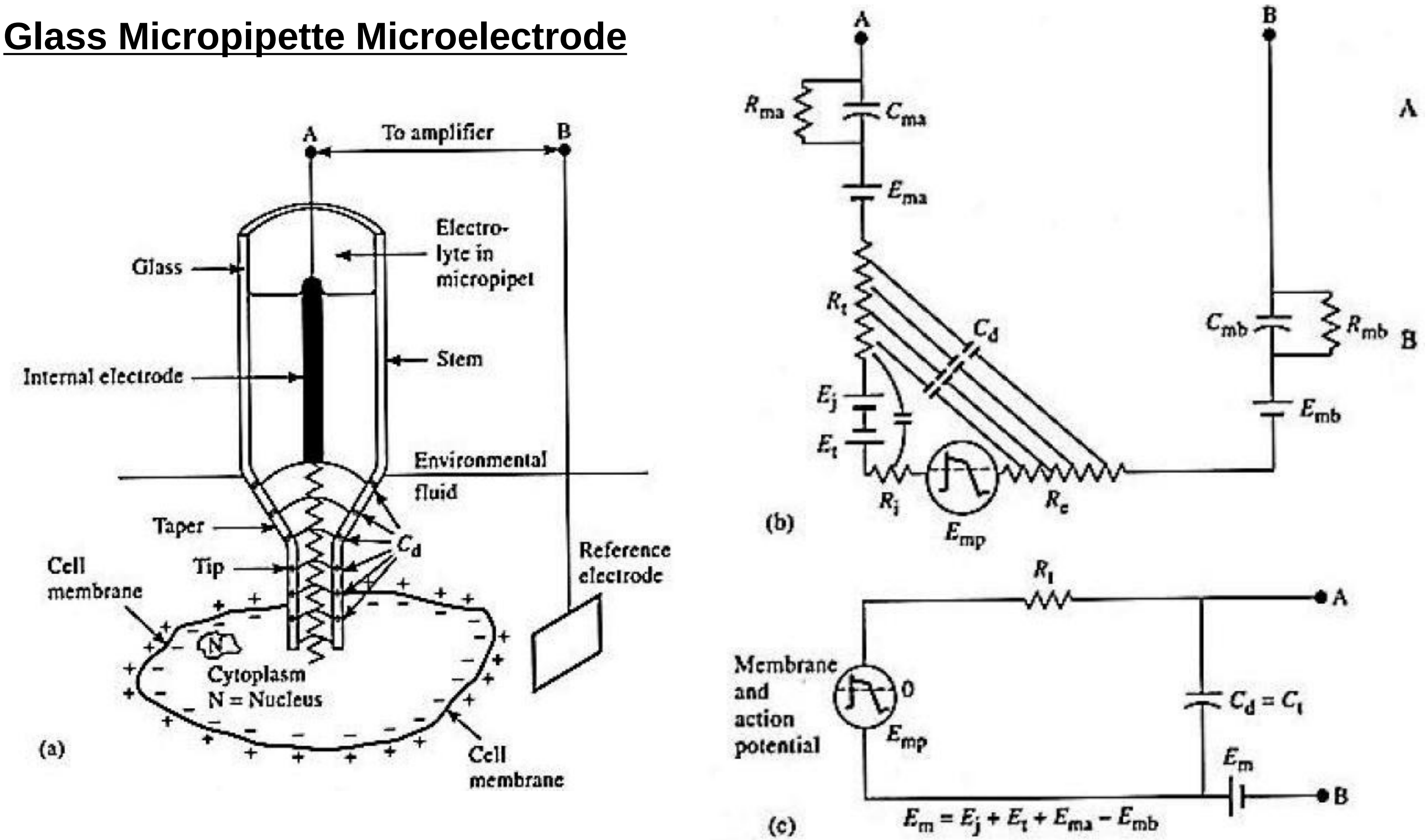
Metal microelectrode with tip placed within cell

Use metal electrode+insulation -> goes to high impedance amplifier…negative capacitance amplifier!

Equivalent circuits

Electrical Properties of Glass Intracellular Microelectrodes

Glass Micropipette Microelectrode



Stimulating Electrodes

Features

– Cannot be modeled as a series resistance and capacitance (there is no single useful model)
– The body/electrode has a highly nonlinear response to stimulation
– Large currents can cause
  – Cavitation
  – Cell damage
  – Heating

Types of stimulating electrodes

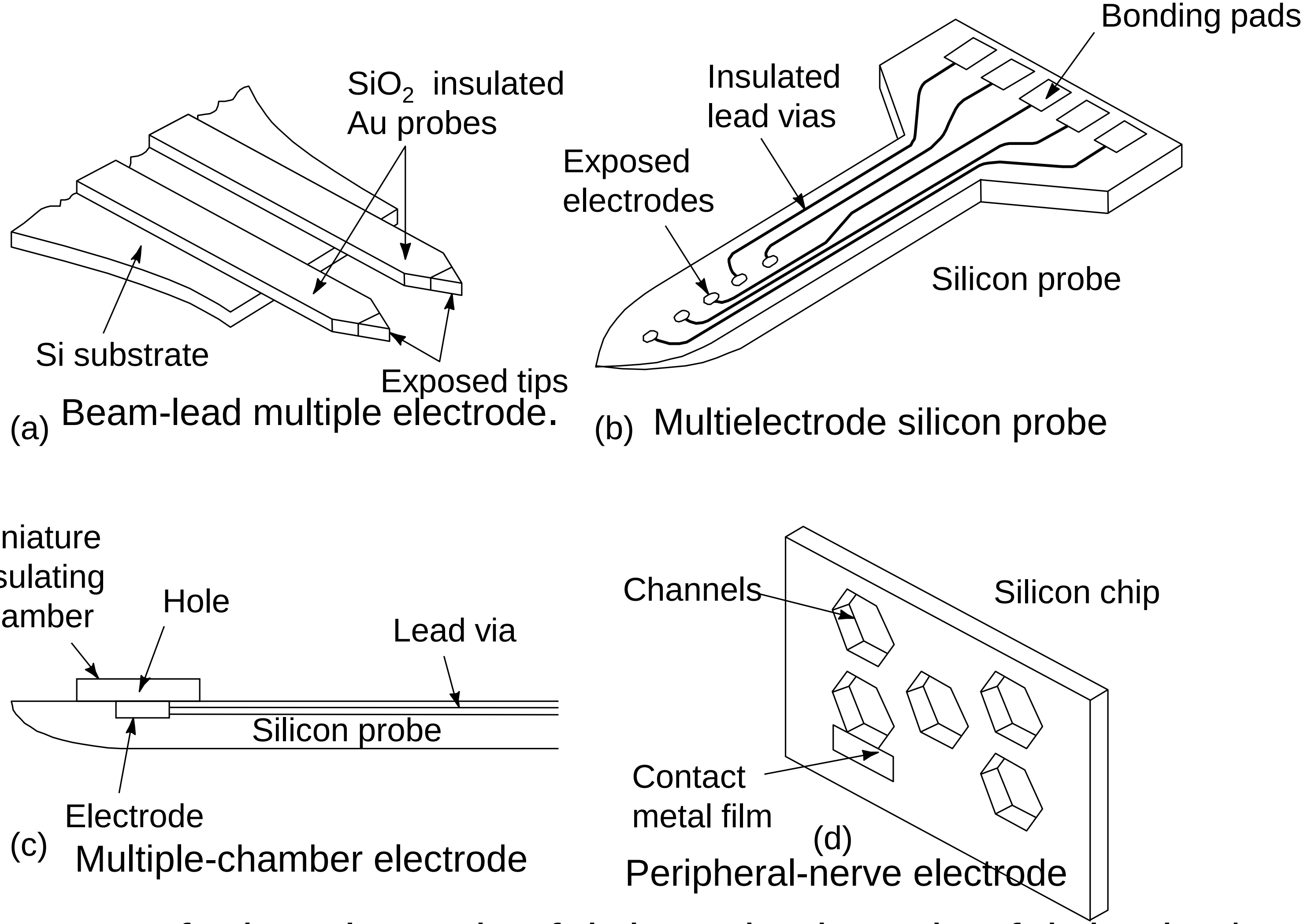
1. Pacing
2. Ablation
3. Defibrillation

Platinum electrodes:
Applications: neural stimulation

Modern day Pt-Ir and other exotic metal combinations to reduce polarization, improve conductance and long life/biocompatibility

Steel electrodes for pacemakers and defibrillators

Microelectronic technology for Microelectrodes



Different types of microelectrodes fabricated using microfabrication/MEMS technology

Michigan Probes for Neural Recordings

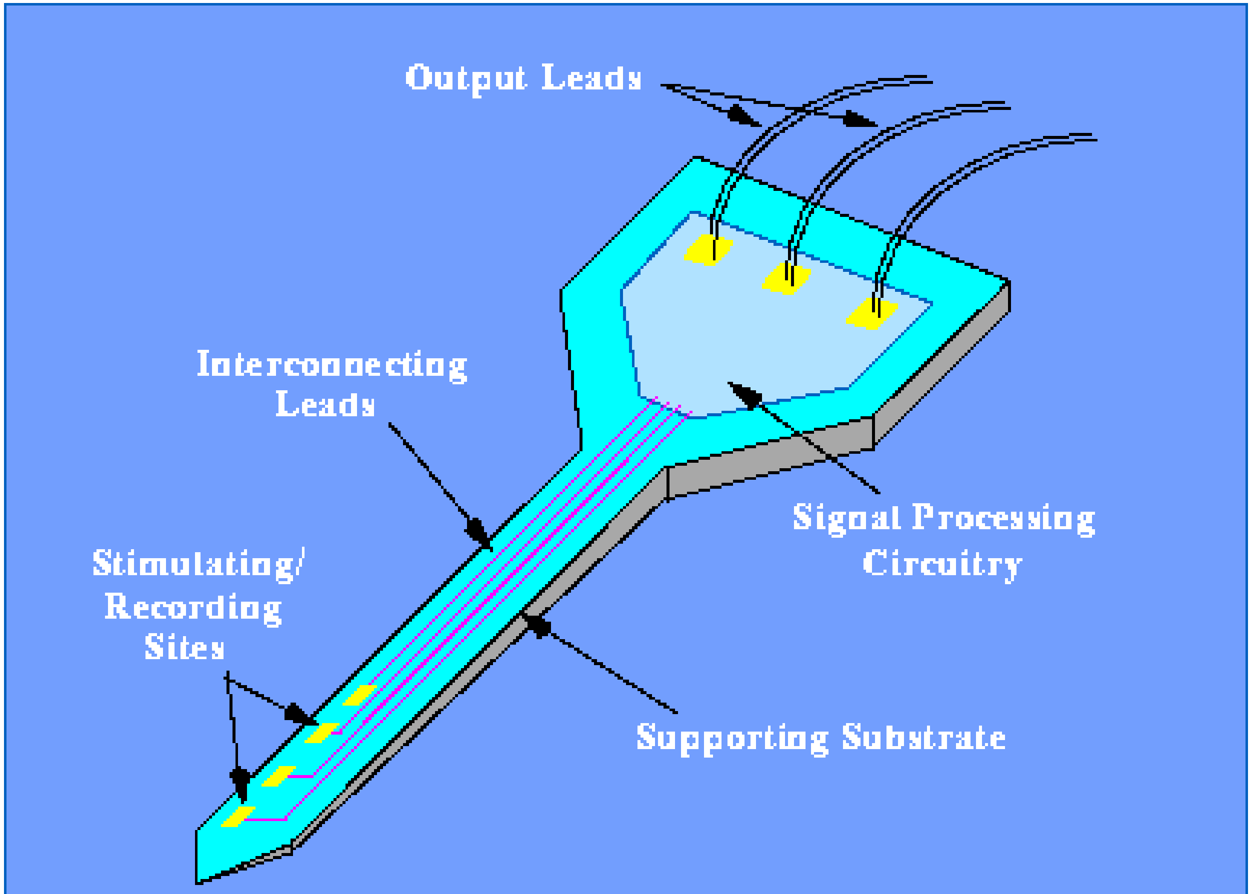


Figure 1: Basic structure of a micromachined multielectrode probe for recording and/or stimulation of the central nervous system.

Neural Recording Microelectrodes

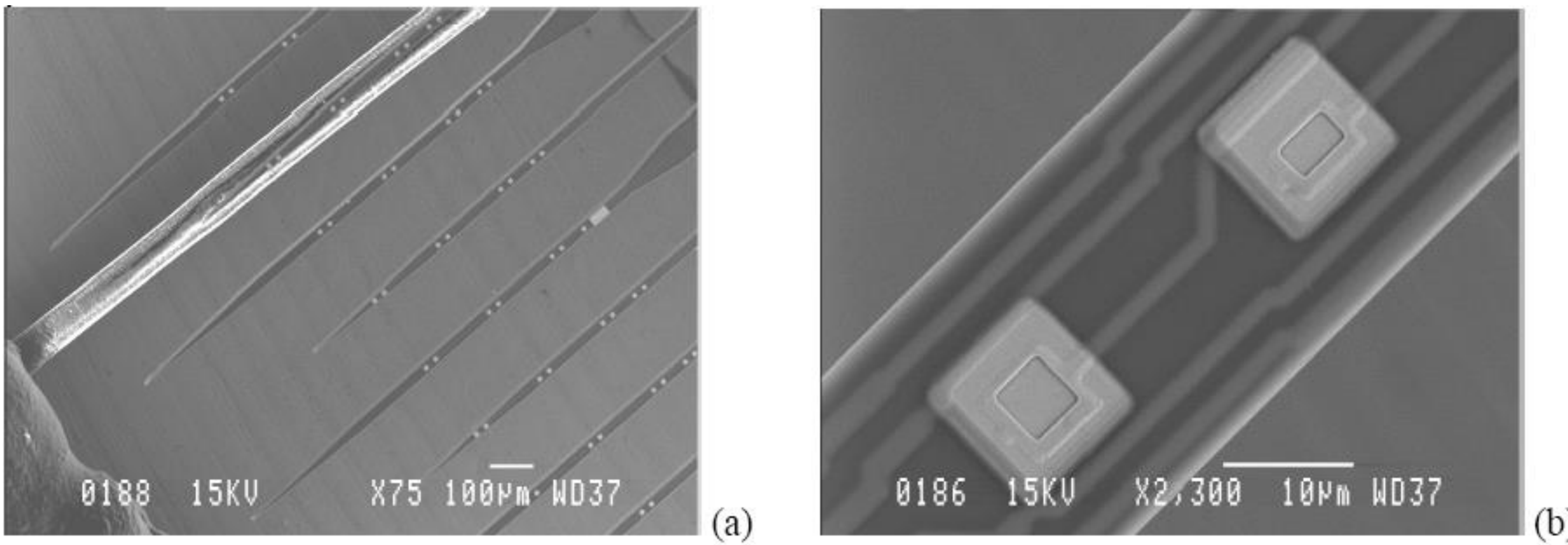


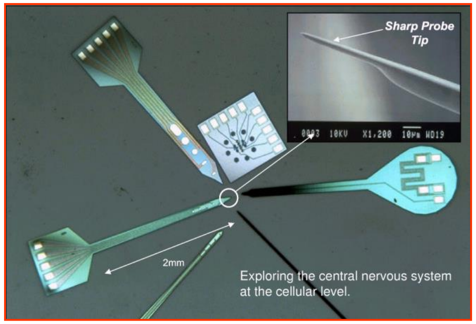
Figure 3. (a) 8 shafts, each with 8 electrodes, compared to a human hair. (b) Close up of 2 electrodes.

Reference :
http://www.acreo.se/acreo-rd/IMAGES/PUBLICATIONS/PROCEEDINGS/ABSTRACT-KINDLUNDH.PDF

In vivo neural microsystems: 3 examples

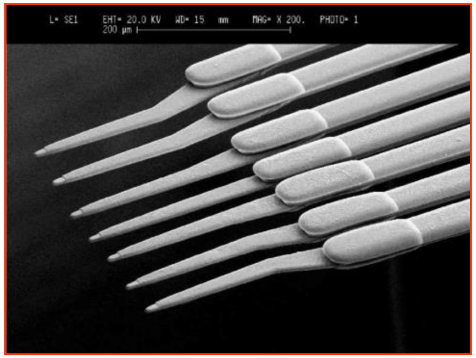
University of Michigan

Smart comb-shape microelectrode arrays for brain stimulation and recording



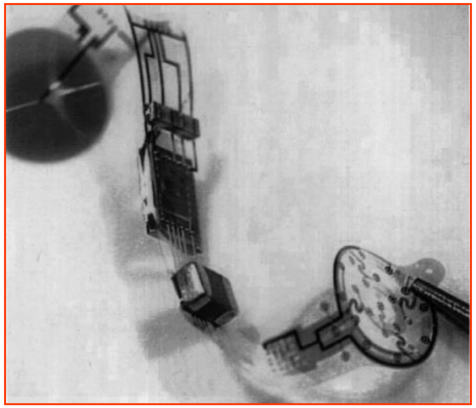
University of Illinois at Urbana-Champaign

High-density comb-shape metal microelectrode arrays for recording

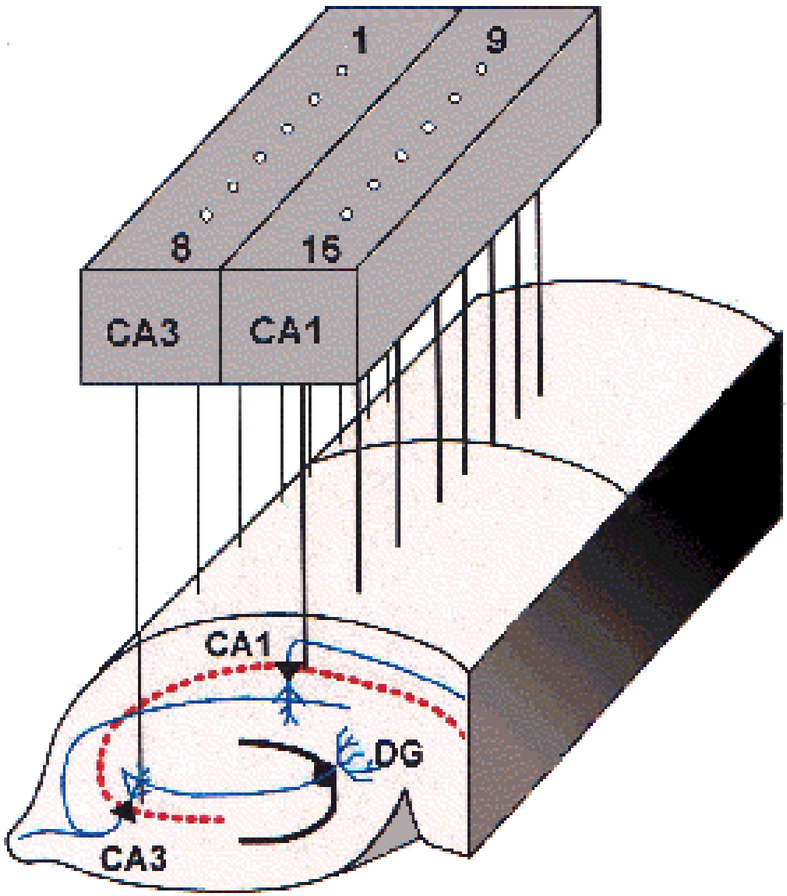


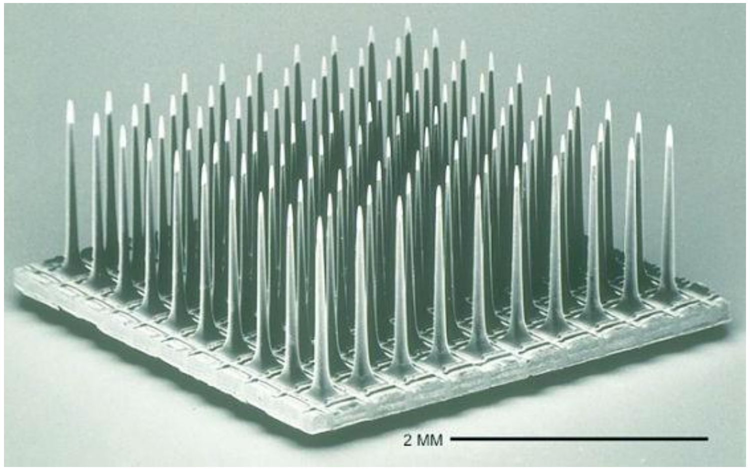
Fraunhofer Institute of Biomedical (FIBE) Engineering

Retina implant



Multi-electrode Neural Recording





Reference :

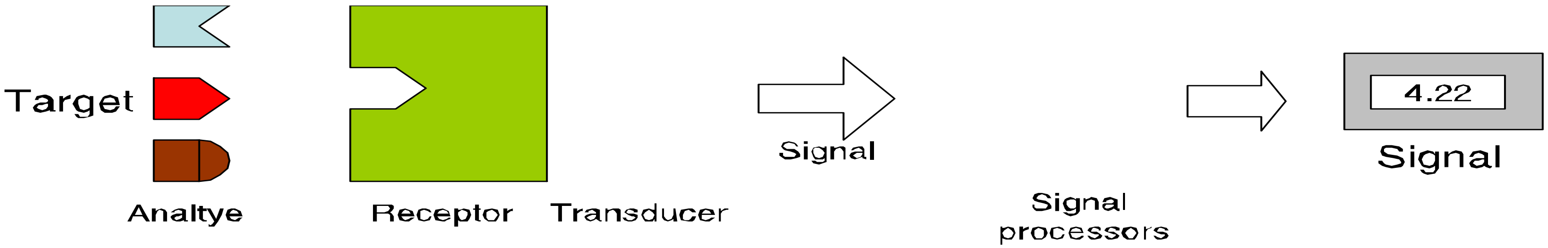
http://www.cyberkineticsinc.com/technology.htm

Reference :
http://www.nottingham.ac.uk/neuronal-networks/mmep.htm

Biosensors

Wei-Chih Wang
Southern Taiwan University of Technology

Biosensors



Analyte: substances to be measured

Small molecules: sugars, cholestrol, glutamic acid, phosphate, etc.

Macro molecules: amino acid (DNA, RNA), peptide (protein, antibody, enzyme)

Receptor: sensing element responds to substance being measured, interaction is highly selective.

Enzyme, antibody, cells

Transducer: device converts physical or chemical changes due to analyte-receptor reactions to eletronic signals whose magnitude is proportional to the amount of the analyte

Electrochemical (potentiometric, voltammetric, conductimetric)

Optical (fluorescence, absorbance, light scattering, refractive index)

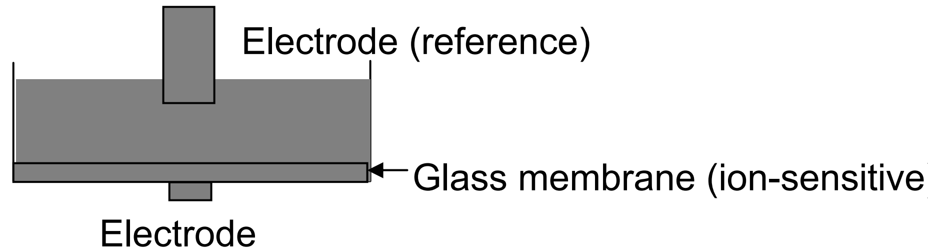
Field effect transistor

Mechanical, thermal, Piezoelectric, SAW, Magnetic

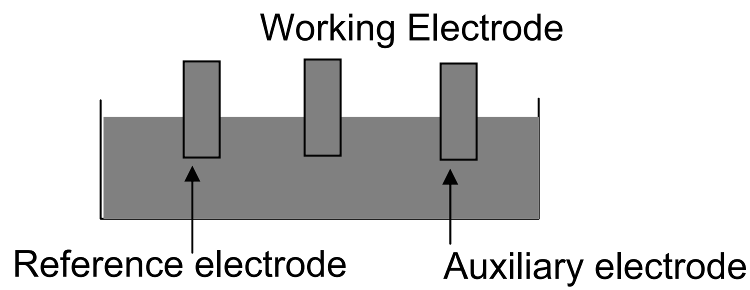
Signal processor: amplifier, filtration, correlation etc.

Transduction Methods: Electrochemical

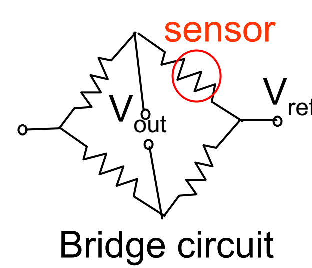
-Potentiometry :
the measurement of a cell potential at zero currents

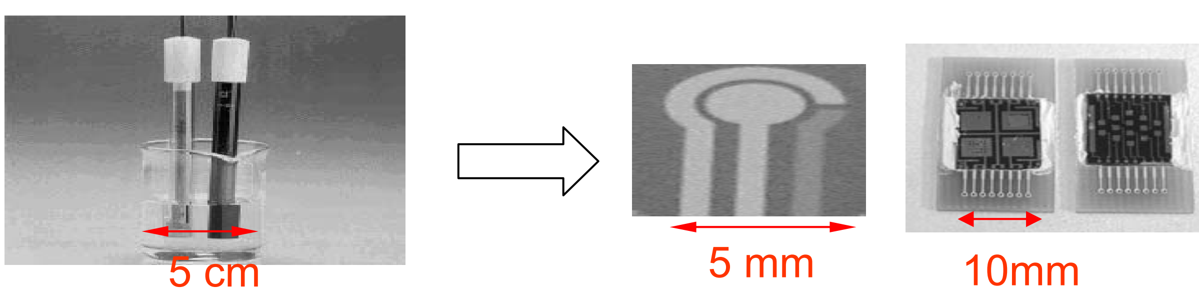


-Amperometry
in which an oxidizing (or reducing) potential is applied between the cell electrodes, and the cell current is measured



-Conductometry
where the conductance of the cell is measured





Ion Selective Field Effect Transistor

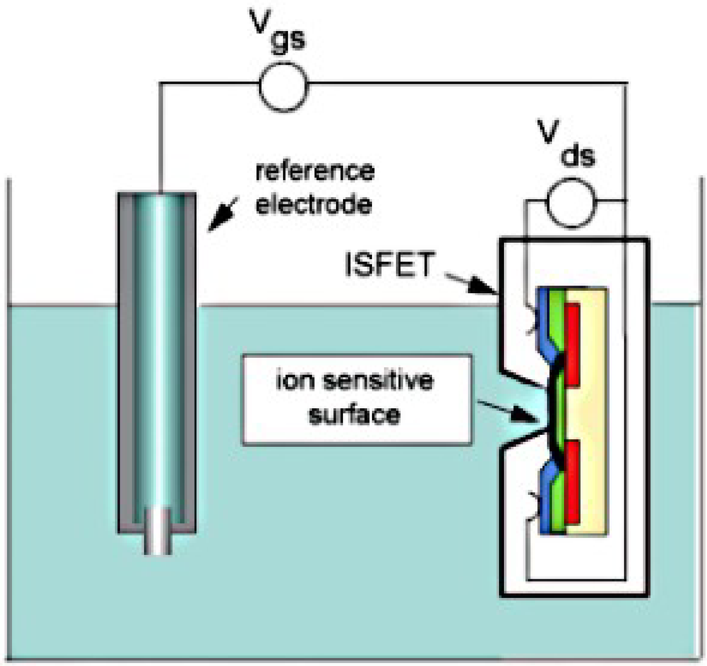
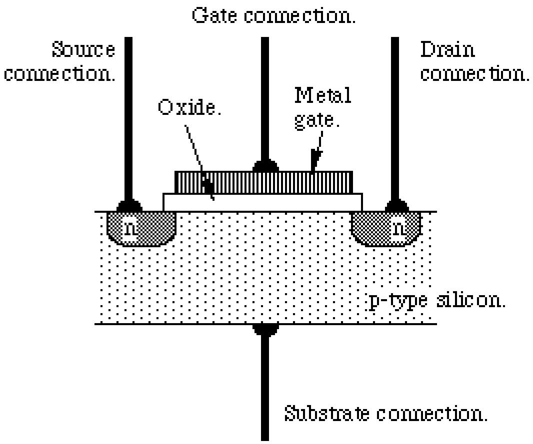
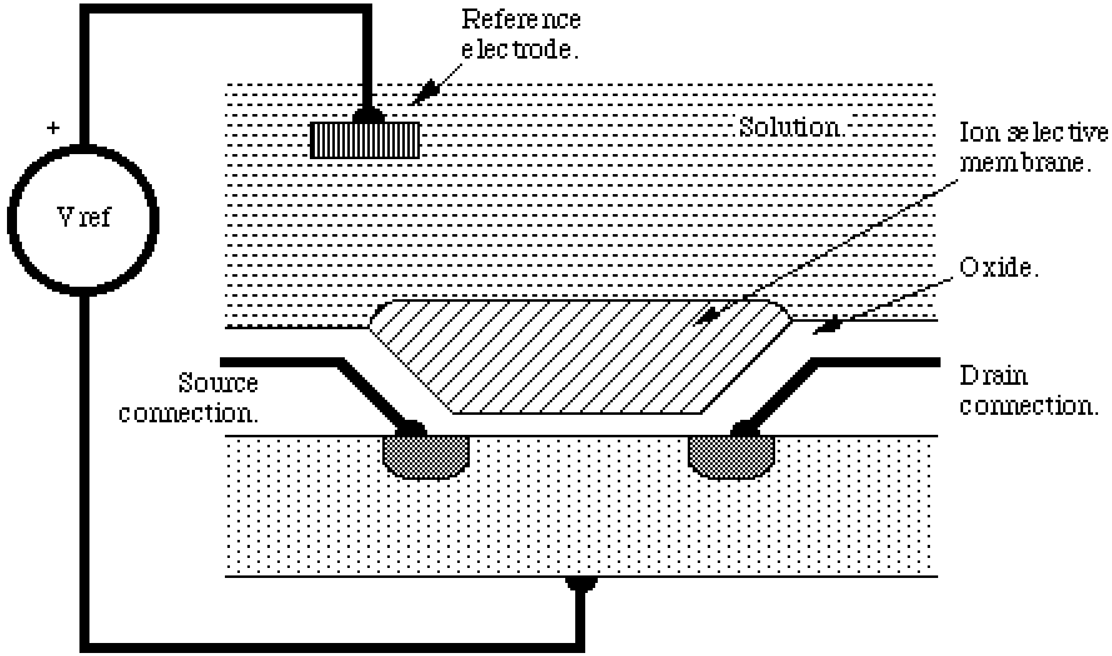


Fig.2: Schematic representation of an ISFET pH measuring system

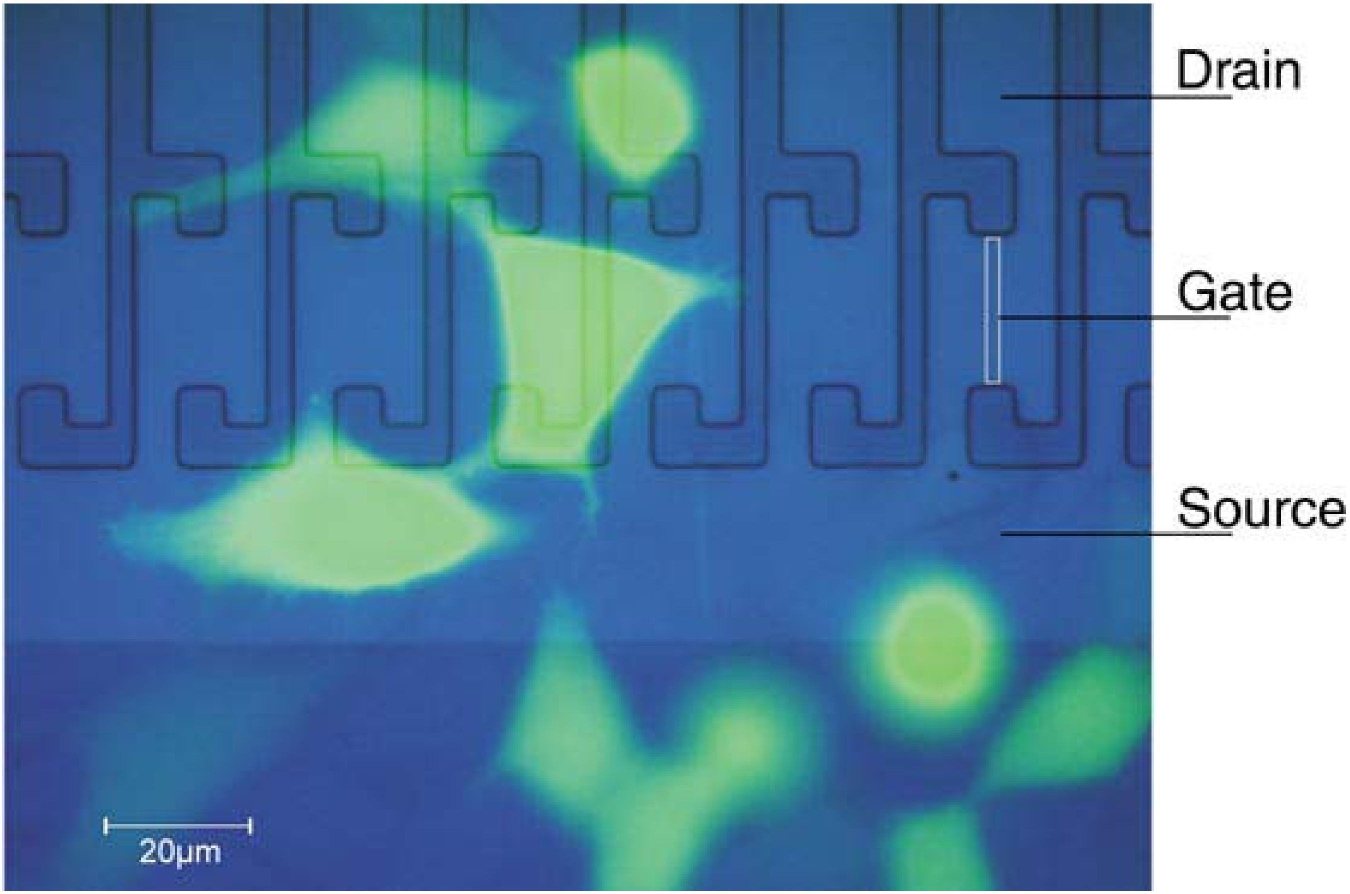


ISFETs sense the concentration (activity level) of a particular ion in a solution. Gate metal is replaced with an ion selective membrane.



Current from source to drain related the gate potential

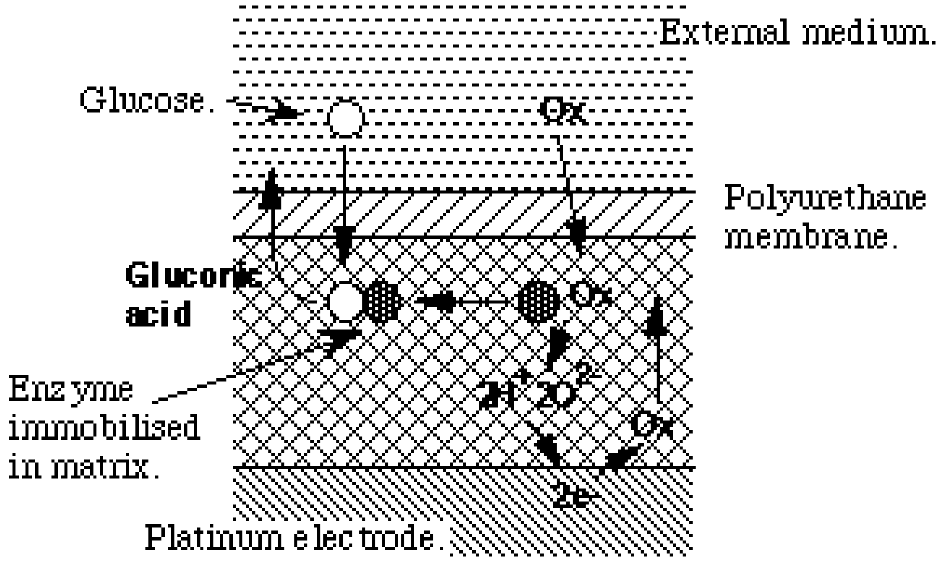
When there is a high concentration of positive ions in the solution, a lot of them will accumulate on the gate, widening the channel between the source and drain. With a low concentration of positive charged ions, the channel will be narrow.



(Fronherz, 2001)

The chip with cultured HEK293 cells is illuminated with blue light and observed through a filter that transmits some light reflected from the chip and the emission of green fluorescent protein used as a reporter for the transfection with maxi-K_{Ca} channels.

Enzyme-based biosensor
glucose oxidized based sensor



Optical Sensors for Chemical or Biochemical Sensing

- Light application for monitoring tissues and cells:

- A multi-parameter sensor-chip-based system

Advantages:
- sensitivity
- simple and compact
- **noninvasive !**

Integration of optical sensors into microfluidic system

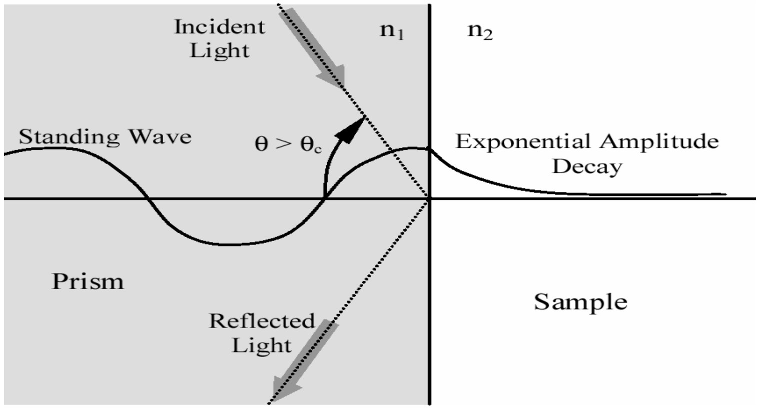
- For use in optical microscopy and cellular biology
- Measure the chemical properties of cells or monitor chemical changes that take place within cells as they respond to external changes in their environment and to internal changes that occur in embryonic cells as an organism develops (on-line monitoring)

Transduction Methods : Optical

- Types of measurements
  - -Absorbance(Oligo260nm, Peptide280nm)
  - -Fluorescence
  - -Refractive index
  - -Light scattering
- Changes measured
  - -Intensity
  - -Frequency
  - -Phase shift
  - -Polarization
- Types of components
  - -Fiber optics
  - -Wave guides
  - -Photodiode
  - -Spectroscopy
  - -Charge coupled device (CCD)
  - -Single photon APD
  - -Interferometers

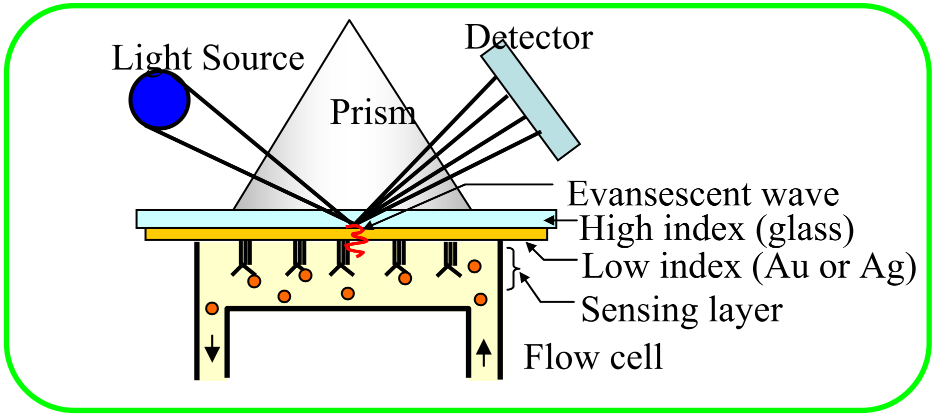
Optical Biosensor Basing on Evanescent Wave

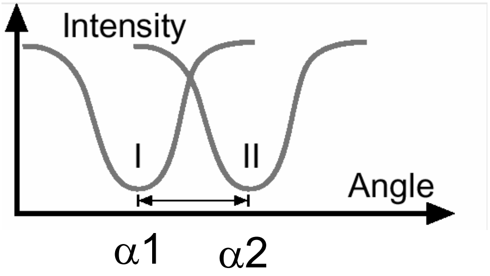
Evanescent Wave



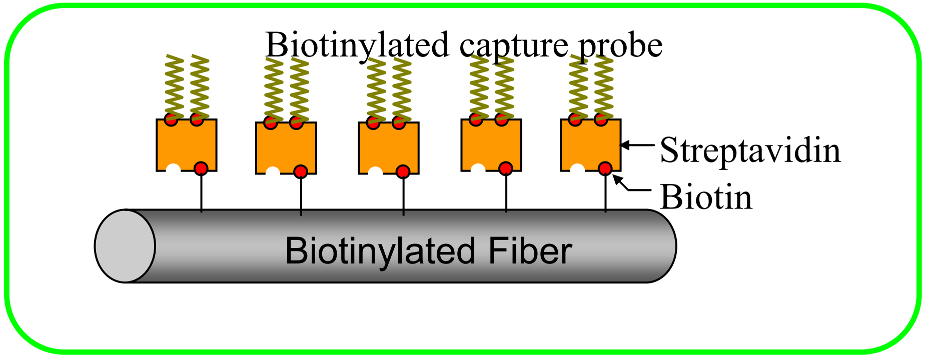
- Separation between surface and bulk
- Noise reduction due to small observation volume

Surface Plasmon Resonance (SPR)

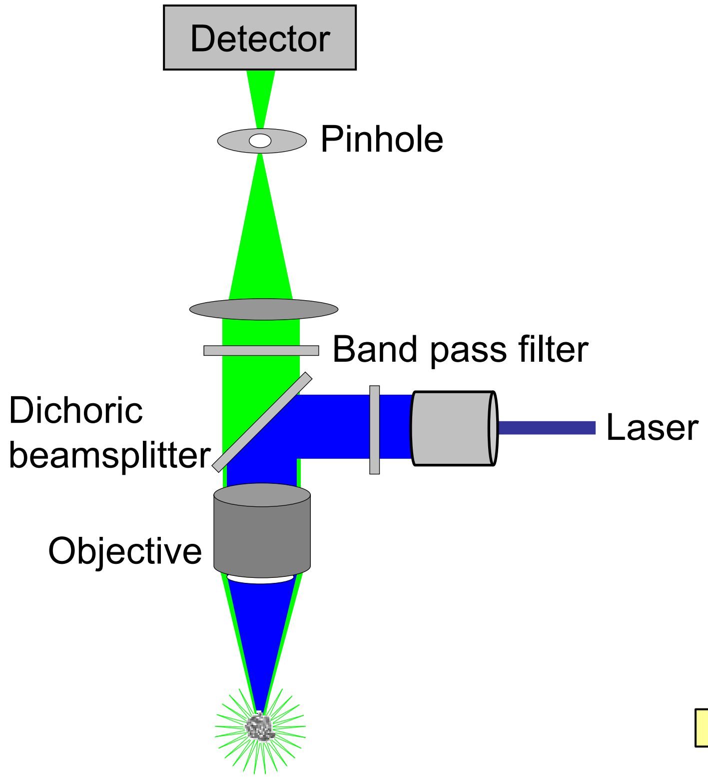




Evanescent Wave Fiber Optic Sensor



Laser Induce Fluorescence (LIF) Based Detection

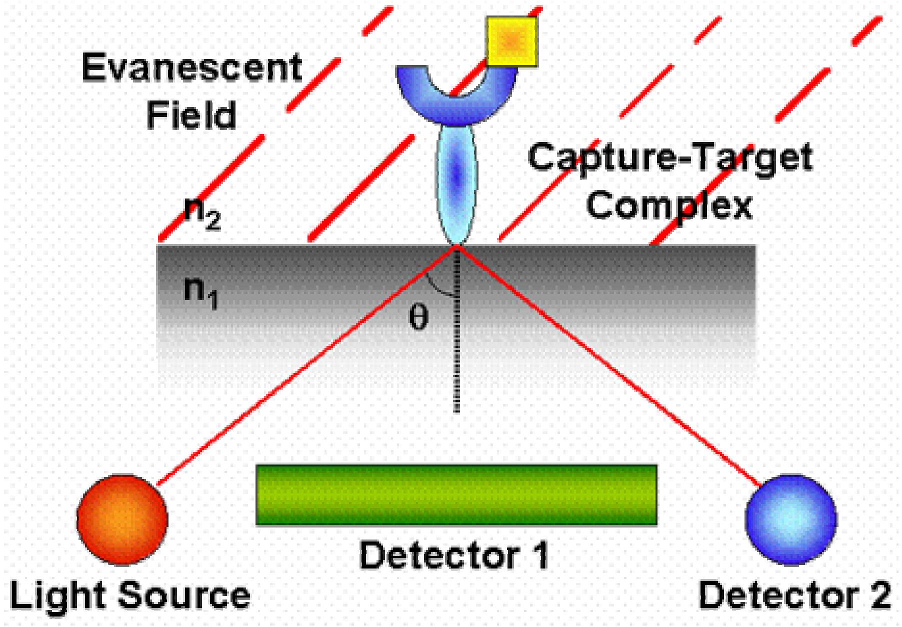


Extremely High Sensitivity

- **Very small probe volume (< 10^{-15}L)**
  - -Less Raman scattering noise from solution
  - -Less background luminescence
- **Monochromatic excitation**
  - -Noise from light source can be efficiently filtrated

⇨ Enhance Signal to Noise Ratio

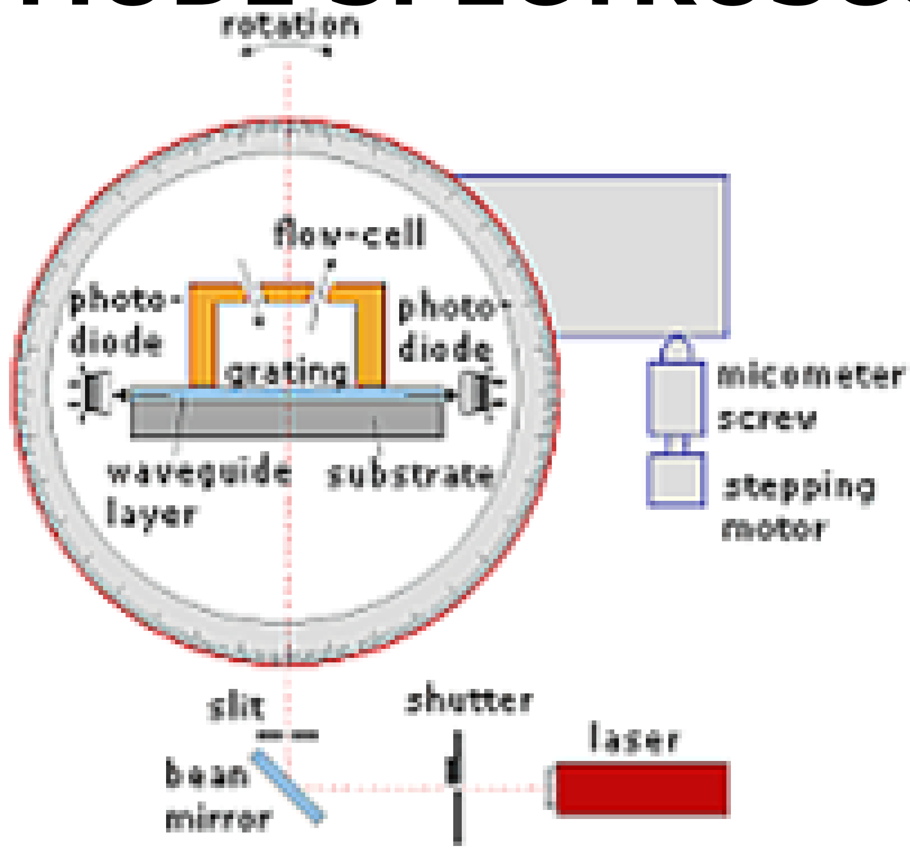
Regenerable biosensor



(Sapsford K 2002)

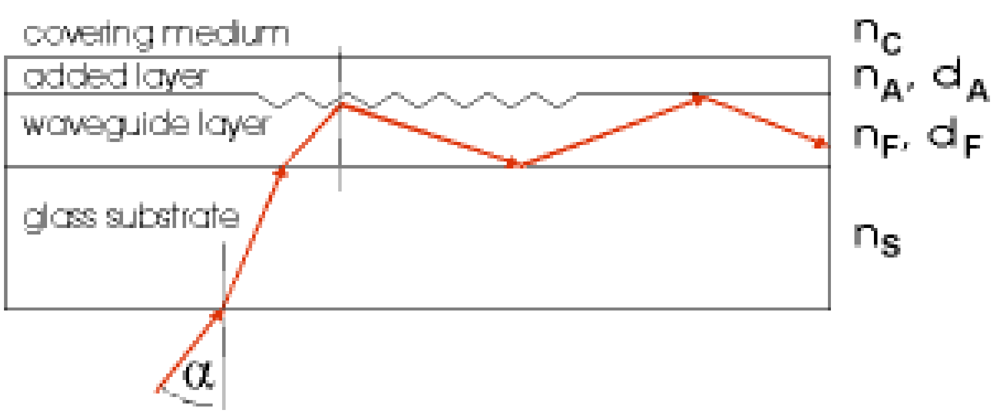
- Electrochemical control of the binding and dissociation of antibody-antigen
- Total internal reflectance fluorescence (TIRF) spectroscopy sensing techniques used

OPTICAL WAVEGUIDE LIGHTMODE SPECTROSCOPY

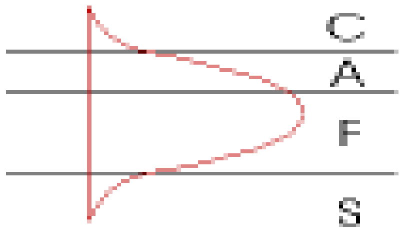


Microvaccum Inc.

Theory and Models

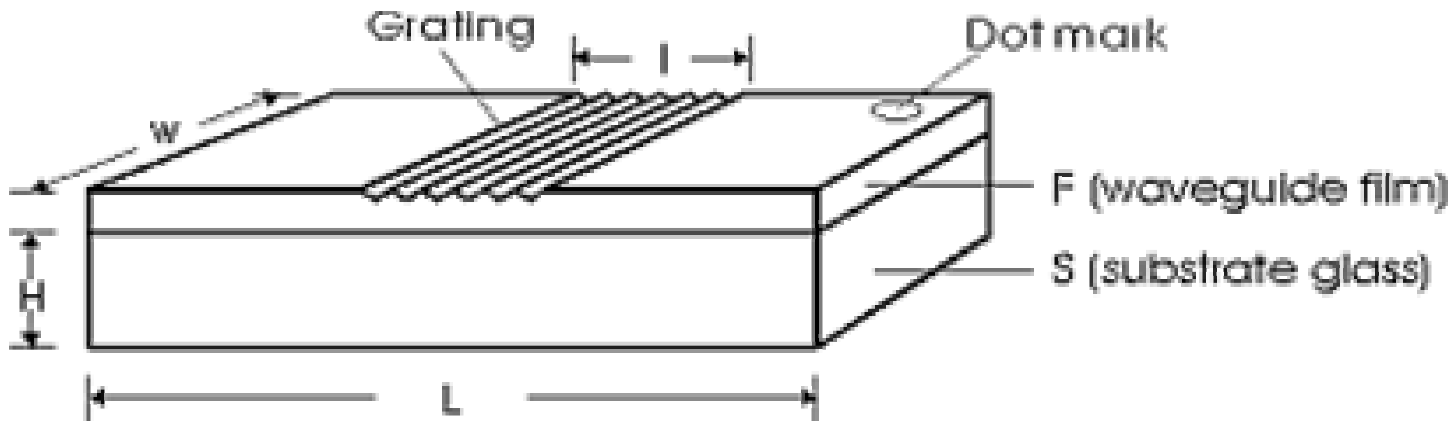


Ray-optic representation of a coupled and guided wave

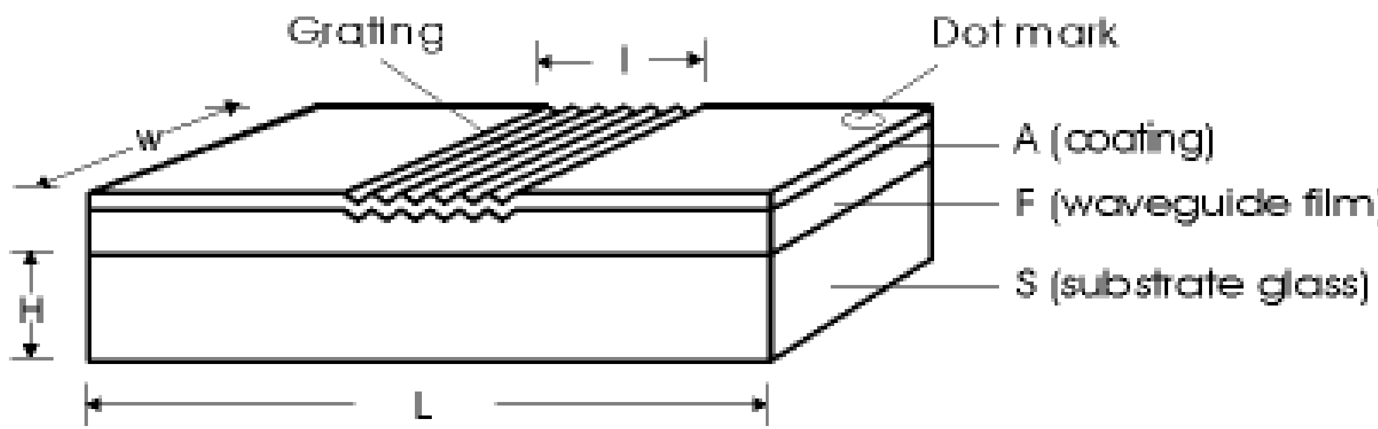


Electromagnetic field distribution for a zeroth mode

Microvaccum Inc.

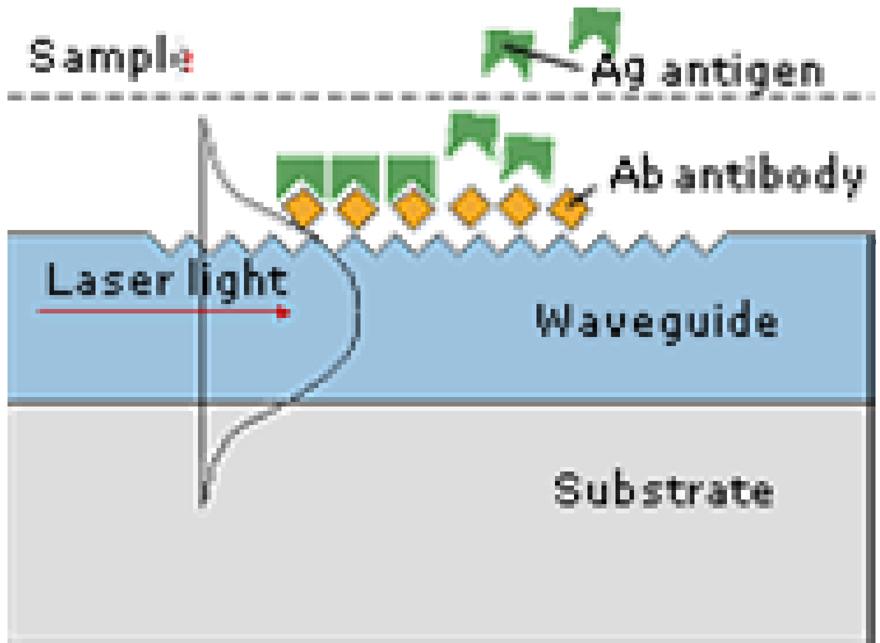


Microvaccum Inc.



Microvaccum Inc.

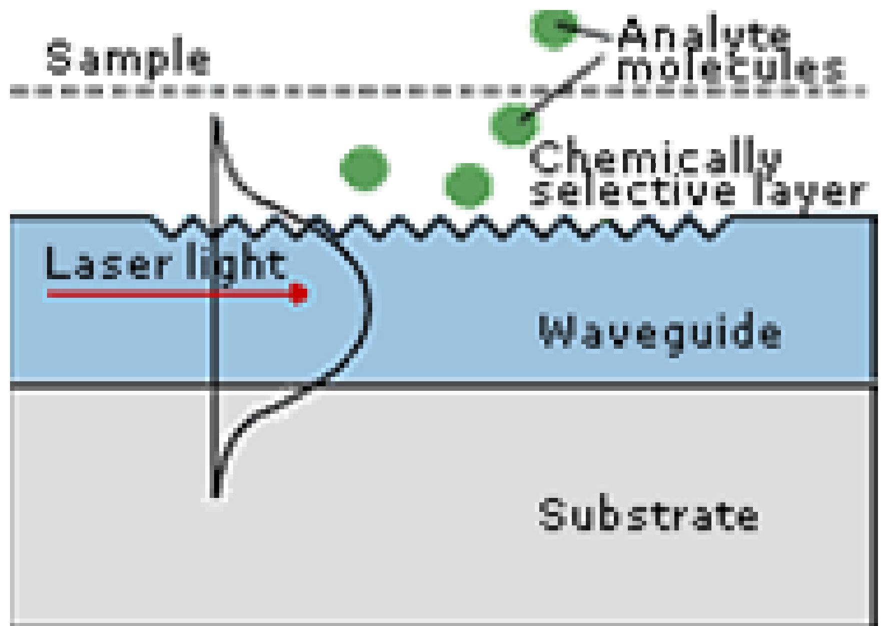
Immunosensor



Microvaccum Inc.

Monomolecular chemoresponsive coating, which consists of immobilized antibody (Ab) molecules, that bind the corresponding antigen (Ag) molecules.

Chemosensor

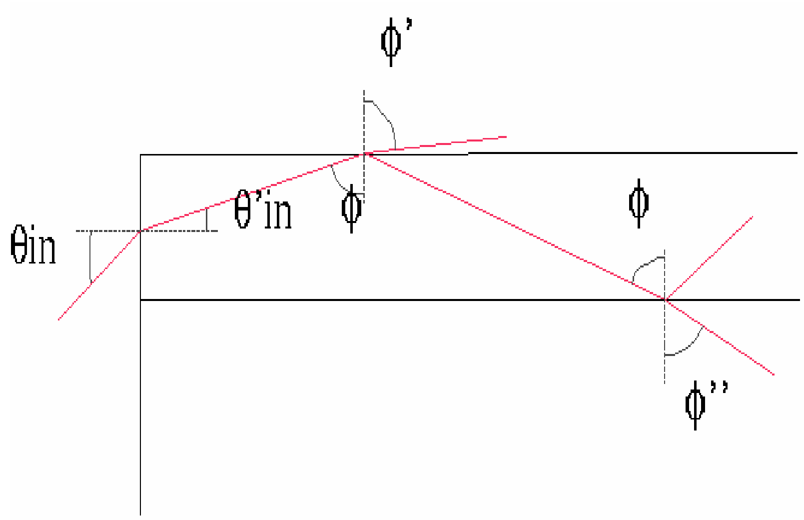


Microvaccum Inc.

With a typically 0,1-1 mm thick chemoresponsive layer whose refractive index is changed by binding the analyte molecules.

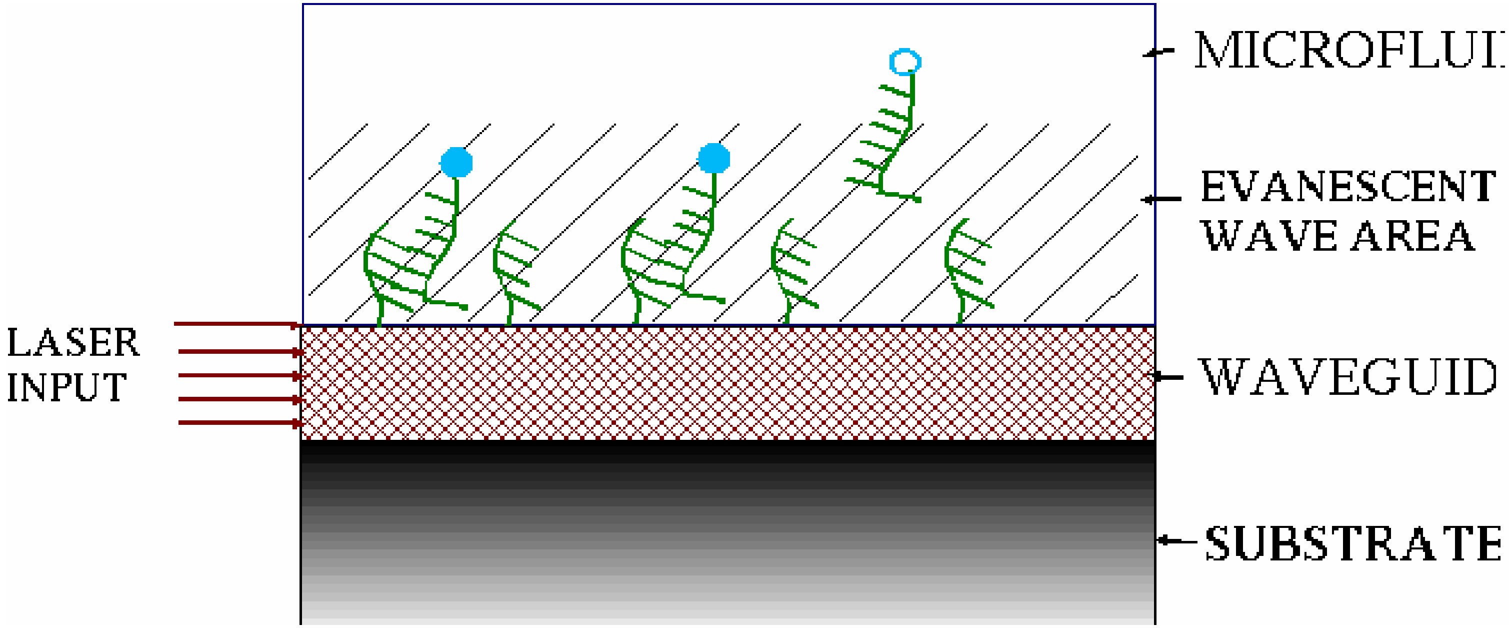
Proposed Optical Biosensor

- Components
  - Waveguide
  - Microfluidic channels
- How it works
  - based on total internal reflection



What to detect?

- DNA
- Antibodies
- Other molecules or chemicals



Biochemical Sensors

- Oxygen sensor- oxygen regent sensor, (immobilized hemoglobin which changes color with absorbed oxygen), oxygen reflectance spectroscopy .
- Carbon dioxide sensor- measured by monitoring pH of a bicarbonate-carbonic acid equilibrium mixture, according to the mass-reaction equation.
- Surface reaction measurement (i.e. chemicaly linked to waveguide in a manner which preserves the specific binding activity, transmission properties of guide are used to meaure antibody-antigen reaction) light scattering, fluorescence, absorption
- Flow sensor (laser-Doppler, interferometer)
- Glucose detector (viscosity, absorption, reflection)
- Concentration
- pH sensor (hydrogen ion-pearmable membrane enclosing a colorimetric pH indicator- optical sensor monitoring changes in reflectance as dye responds to pH changes)
- Acidity sensor

- Turbidity (or scattering) measurement (determination of impurities in liquids and the measurement of particle size- oil in water monitoring reflectance probe)

Applications for Medical Instrumentation

- Endoscopes
- Laser surgery and therapy
- Angioplasty
-Temperature sensors (hyperthermia, cardiac monitoring, by thermodilution, tissue thermal damage monitoring)
-Pressure sensor (cardiovascular, intracranial,neurology urodynamics)
- Chemical sensors:blood oximetry, pH, pO_2, pCO_2 (metabolic and respiratory problems, blood an tissue oxygen content, oxygen,hemoglobin dissociation curve)

Material Requirements (Optical)

- Low loss
  - absorption
  - scattering
- Low fluorescence
- High refractive index
- Easy to fabricate

Material Requirements (Fluidic)

- Biocompatible
- Hydrophobic/Hydrophilic
- Sufficient bond strength with optic components
  - Low temperature bonding necessary

Biocompatibility

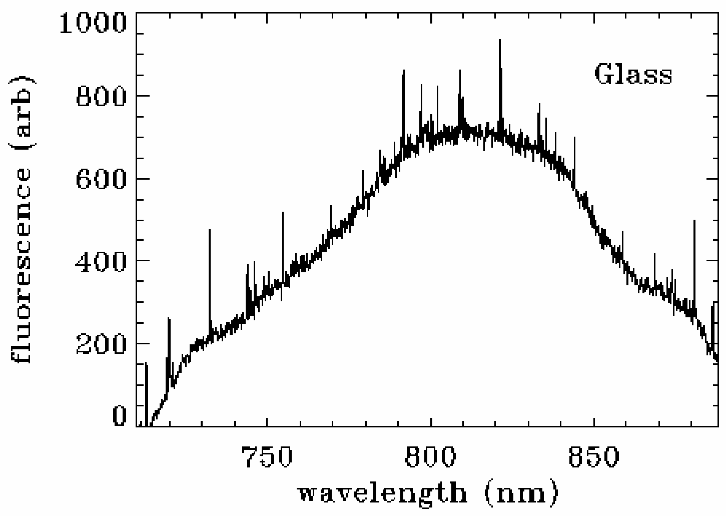
- The interface between live cells and sensor is one of the key issues of the design
- Study of biocompatible materials (i.e. PEG, PEO avoid adsorption of proteins, clogging with cells, immune response etc.)
- Study of gas or molecule absorbing materials (i.e. thermally responsive biopolymer ppNIPAM, enzyme,antibody, cells)

Possible Materials

- Present
  - Si/Si_3N_4
  - glass/ion-exchange
  - PDMS
- Future
  - PMMA
  - Mylar
  - Teflon

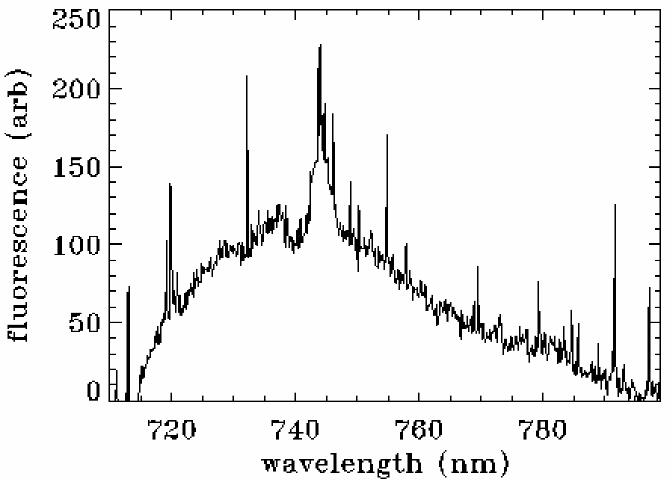
Material Properties-Ion Exchange Glass

- Loss: 0.0006/cm
- Fluorescence: 510112 (arb)
- n = 1.47
- Biocompatible: Yes
- Hydrophilic



Material Properties - PDMS

- Loss: 0.0008/cm
- Fluorescence: 36383 (arb)
- n = 1.5
- Biocompatible: Yes
- Hydrophobic



Fabrication Techniques

Bulk micro-machining

- Wet etching
- Vapor-phase etching
- Plasma/reactive ion etching
- µmolding
- Laser etching
- screen printing

Surface micro-machining

- Thin film process (sol-gel, wet etching, dry etching, film deposition, lift-off patterning, epitaxial growth etc.)
- sacrificial process (phase-change release, plasma etching, sacrificial layer)
- bonding process (anodic bonding, silicon fusion etc.)
- laser etching
- E-beam
- LIGA

Questions	opt1	opt2	opt3	opt4
1.In direct comparison method the unknown quantity is compared directly with	primary standard	secondary standard	primary or secondary	working standard
2. Indirect In comparison method the unknown quantity is compared directly with	primary standard	secondary standard	standard meter	none
3.Based on principle of operation , the method of measurement is classified as	null method	deflection method	null & deflection	none
4.Deflection in the scale is the type of	deflection method	null method	both a & b	none
5.Balancing principle is used in the	deflection method	null method	both a & b	none
6.Galvanometer comes under which method	deflection method	null method	direct	indirect
7.The output of the transducer may be	voltage	current	air pressure	all the above
8.Strain gauge along with wheatstone bridge is called	sensor	transducer	device	none
9. Which method offers high accuracy of measurement?	deflection method	null method	deflection & null	none
10. The signal conditioning includes	amplification	demodulation	filtering	all the above
11.To carry nout calibration one needs	standard instrument	input source to produce measured value	standard instrument and input source	instrument
12. In static calibration , all other variables are___________ and _________the one in focus	constant, varied	varied, constant	either a or b	none
13.The error can be classified into howmany categories.	2	3	5	4
14.Errors due to human factors are called	Gross error	Systematic error	Random error	none
15. Gross errors are eliminated by	autoranging of digital meters	proper selection of instrument	proper computation	all the above
16. The error due to changes in external conditions is called	Gross error	Systematic error	Random error	none
17.Systematic error can be classified into howmany categories.	2	3	5	6
18. The error arises out of the changes in the properties of the component used in the instrument.	instrumental	environmental	static	dynamic
19.Theerror are due to the changes in the environmental conditions	instrumental	environmental	static	dynamic
20. The errors are caused by the limitations of the measuring device	instrumental	environmental	static	dynamic
21. Tjhe errors are caused by the instrument slow response	instrumental	environmental	static	dynamic
22.Which is the unpredictable error	Gross error	Systematic error	Random error	none
23. The systematic way of specifying the uncertainity is called	error	statistical method	accuracy	none
24. The statistical method uses terms like	arithmetic mean	deviation	median,mode	all the above
25. The average value of reading is given by	arithmetic mean	deviation	median	mode
26. The departure of a given reading from the arithmetic mean of group of reading is called	arithmetic mean	deviation	median	mode
27. The square of the standard deviation is called	variance	deviation	deviation square	mode
28. The middle value of the set when it is arranged in ascending or descending order is called	arithmetic mean	deviation	median	mode
29. The value which occurs most frequently in a set of observations is called	arithmetic mean	deviation	median	mode
30. The precise measurement is possible in	Gaussian curve	Crude method	both a & b	none
31. The bell shaped curve is called	Gaussian curve	bell curve	inverted U curve	both a & b
32. Which of the following are statistical method of analyzing the error	normal distribution of error	probable error	limiting error, odds	all the above
33. The probable error has the value as	+s	-s	± 0.6745s	both a &b
34. The maximum deviation is called	probable error	limiting error	odds	uncertainity
35.The relation between probability of occurance and odds is given by	odds(odds+1) = probability of occurance	odds(odds-1) = probability of occurance	odds(odds*1) = probability of occurance	odds(odds/1) = probability of occurance
36. The transducer can be classified into how many different ways	3	2	4	5
37. Classification based on physical effect employed includes	variation of resistance	variation of inductance	variation of capacitance	all the above
38. Potentiometer and strain gauge are based on the principle of	variation of resistance	variation of inductance	variation of capacitance	all the above
39. Induction Potentiometer and LVDT are based on the principle of	variation of resistance	variation of inductance	variation of capacitance	all the above
40. Capacitor microphone is an example of	variation of resistance	variation of inductance	variation of capacitance	all the above
41. The piezoelectric crystal is	quartz	Rochelle salt	both a & b	none
42. The deformation obtained when elastic member is subjected to mechanical stress is called	hall effect	elastic effect	piezoelectrie effect	magnetostrictive effect
43. The classification based on quantity converted includes	temperature transducer	pressure transducer	flow transducer	all the above
44. Based on source of energy for the output, transducer are classified into______types	3	2	4	5
45.Which absorbs energy from the input medium and converts directly into the output signal	active	passive	both a & b	none

46. which uses the energy it absorbs from the input medium as acontrol signal to transfer energy from the power supply to produce a proportional output	active	passive	both a & b	none
47. An example of active transducer is	thermocouple	strain gauge	both a & b	none
48. An example of passive transducer is	thermocouple	strain gauge	both a & b	none
49. Units are broadly classified into how many types	3	2	5	4
50. Units which are fundamental to most other physical quantities is	fundamental unit	derived unit	both a & b	none
51.The units which are expressed in terms of fundamental unit is called	fundamental unit	derived unit	both a & b	none
52. Example of fundamental unit is	length	mass	time	all the above
53. Example of derived unit is	area	mass	velocity	both a & c
54. There are _____ fundamental unit,_____ supplementary unit and ______ derived unit	6,2,many	7,2,many	5,4,many	2,6,many
55.The unit of luminous intensity is	cad	candela	both a & b	cd
56. International Bureau of weights and measures is located at	Paris	India	England	Japan
57. Primary standard are maintained by	National standards laboratory	International laboratory	Regional laboratory	both b & c
58.In India, National Physical Laboratory is located at	Mumbai	New Delhi	Calcutta	Chennai
59. The unit of solid angle is	degree	steradian	radian	none
60. The fundamental unit of mass is	gram	kilogram	milligram	none

UNIT II

Questions	opt1	opt2	opt3	opt4	
______________ of the transducer is essential for the proper choice of transducer.	Characteristics	Input	Output	selection	
The performance Characteristics can be broadly classified into ________ categories	4	2	5	3	
The two characteristics of transducer are	static	dynamic	unstable	static&dynamic	
____________ characteristics gives quality of measurement while the meseaured quantities are either constant or vary slowly	static	dynamic	sensitivity	linearity	
___________ characteristics gives quality of measurement while the meseaured quantities are vary rapidly with time	static	dynamic	sensitivity	linearity	
The dynamic characteristics are described by	linear differential equation	differential equation	non-linear differential equation	both a& c	
The differential equation becomes _____________ for static characteristics	linear	non-linear	both a & b	zero	
Which of the following are static characteristics	senstivity	linearity	threshold	all the above	
Which of the following are static characteristics	hysteresis	resolution	accuracy	all the above	
____________ is defined as the slope of the static calibration curve	senstivity	linearity	threshold	resolution	
If the calibration curve is not a straight line then the sensitivity will ____________ with input value	same	vary	equal	both a & c	
The sensitivity is expressed as	output unit/ input unit	input unit/ output unit	response / output	none	
The sensitivity of mercury in glass thermometer is	mm/ º C	mm/ kpa	mm/s	none	
The sensitivity of pressure gauge is	angular degree/ kpa	angular degree/ º C	angular degree/ s	mm/ kpa	
__________ relationship is most desirable for many applications	non-linear	linear	good	accurate	
___________ is a measure of the maximum deviation of the potted transducer response from a specified straight line	senstivity	linearity	threshold	resolution	
The straight line for plotted calibration curve can be determined by	least square fit	squares fit	differential equation	all the above	
In least squares method, the best-fit straight line is determined by choosing the	sum of squares of deviation	minimum of sum of squares of deviation	maximum of sum of squares of deviation	squares of deviation	
The linearised relation between X and Y can be expressed as	Y= aX+b	Y= aX-b	X= aY+b	X= aY-b	
Linearity can be expressed as	Percentage of actual reading	Percentage of full scale reading	combination of both a& b	all the above	
Expressing the linearity in the combination of both actual and full scale reading is known as	Dependant linearity	Response	Independant linearity	All the above	
When ξ = 1, the system is said to be	undamped	critically damped	non damped	over damped	
___________ is the degree of closeness with which the given value may be repeadedly measured.	sensitivity	linearity	precision	accuracy	
The deviation from the nominal output in absolute units or a fraction of full scale is called _________	precision error	repeatability error	precision&repeatability	error	
_________ is the closeness to the true value	sensitivity	linearity	precision	accuracy	
When ξ >1, the system is said to be	undamped	critically damped	non damped	over damped	
The minimum value below which no output can be detected	threshold	resolution	range	span	
The change in output is not detected until certain input increment of non- zero arbitary value is exceeded and this is called ___________	threshold	resolution	range	span	

_________defines the smallest measurable input change	threshold	resolution	range	span
The mismatching of input-output curves when input to transducer is increased from zero to full scale and then decreased back to zero is called	threshold	resolution	range	hysteresis
Which of the following members exhibit considerable amount of hysteresis effect	springs	bellows	diaphragms	all the above
The __________ of a transducer is specified as from lower values of input to higher value of input	range	span	hysteresis	resolution
The __________ of a transducer is specified as the difference between the higher and lower limits of recommended input values	range	span	hysteresis	resolution
The __________ effect of a transducer gives a measure of its disturbance on the measuring quantity	loading	sensitivity	linearity	hysteresis
The loading effect is usually expressed in terms of	input impedance	stiffness	input impedance&stiffness	none
The order of a transducer is the ___________ derivative of differential equation	highest	lowest	medium	none
The input-output relationship of a transducer is described by d 3 y(t) / dt3 + 3 d2 y(t)/ dt2 +dy(t)/dt + 4 y(t). The order of this transducer is	3	4	2	1
Which of the following are test inputs	impulse input	step	ramp	all the above
The laplace function of impulse input is	1	K/ S	K/S^2	$2K/S^3$
The laplace function of step input is	1	K/ S	K/S^2	$2K/S^3$
The laplace function of ramp input is	1	K/ S	K/S^2	$2K/S^3$
The laplace function of sinusoidal input is	1	K/ S	K/S^2	$Kw/S^2 + w^2$
The input-output relationship of a zero order transducer is given by	y(t)= kr(t)	a_1 dy(t)/dt +a_0 y(t) = b_0u(t)	a_2 d ^{2}y(t)/dt^2 +a_1 dy(t)/dt +a_0 y(t) = b_0u(t)	none
The input-output relationship of a first order transducer is given by	y(t)= kr(t)	a_1 dy(t)/dt +a_0 y(t) = b_0u(t)	a_2 d ^{2}y(t)/dt^2 +a_1 dy(t)/dt +a_0 y(t) = b_0u(t)	none
The input-output relationship of a second order transducer is given by	y(t)= kr(t)	a_1 dy(t)/dt +a_0 y(t) = b_0u(t)	a_2 d ^{2}y(t)/dt^2 +a_1 dy(t)/dt +a_0 y(t) = b_0u(t)	none
The laplace transfer function of a zero order transducer is given by	Y(S)/ R(S)=K	Y(S)/U(S) = K/ τs +1	Y(S)/ R(S) = (b_0/ a_0)/ (a_2/ a_0 s^2+ a_1/ a_0 s +1))	none
The laplace transfer function of a first order transducer is given by	Y(S)/ R(S)=K	Y(S)/U(S) = K/ τs +1	Y(S)/ R(S) = (b_0/ a_0)/ (a_2/ a_0 s^2+ a_1/ a_0 s +1))	none
The laplace transfer function of a second order transducer is given by	Y(S)/ R(S)=K	Y(S)/U(S) = K/ τs +1	Y(S)/ R(S) = (b_0/ a_0)/ (a_2/ a_0 s^2+ a_1/ a_0 s +1))	none
Example of zero order transducer is	potentiometer	theremocouple	vibration galvanometer	all the above
Example of first order transducer is	potentiometer	theremocouple	vibration galvanometer	all the above
Example of second order transducer is	potentiometer	theremocouple	vibration galvanometer	all the above

UNIT III

Questions	opt1	opt2	opt3	opt4
1.Resistance of the conducting wire is given by	R= ρl/a	R= ρl2/a	R= ρa/l	R= a/l
2.The movement of the slider in the potentiometer can be	translational	rotational	combination of two	all the above
3.In rotary potentiometer, Θ_p is	350°	300	270°	90°
4.The error due to loading in the potentiometer is the ratio of	Rp/Rm	Rm/Rp	2Rp/Rm	Rp/2Rm
5. To resolution in a potentiometer __________ can be used as the resistance element.	single slide wire	double slide wire	double helical	thick wire
6. Resistance of a given length of wire can be increased by _________ the diameter of the wire	increasing	decreasing	either a or b	all the above
7. The practical limit for wire spacing at present times is between	100 to 150	100 to 200	75 to 150	75 to 100
8. The resolution of a potentiometer can be improved by using	multi-turn potentiometer	gears	carbon film	all the above
9.The main source of noise is _________ of the slider	vibration	positioning	material	resistance wires
10.The source of noise in potentiometer are	dirt	wearout products	vibration	all the above
11.The gage factor is _________ change per unit strain	unit resistance	unit capacitance	unit inductance	all the above
12. The poissoins ratio is always between _________	0 and 0.5	0 and 1	1 and 2	1.5 and 2

13. The common types of strain gauges are made of	Advance	Isoelastic	both a and b	Nichrome
14. The Gauge factor of strain gauge is made of Advance is ____________	1	2	3	3.5
15. The Gauge factor of strain gauge is made of Isoelastic is ____________	1	2	3	3.5
16. ____________ strain gauge can be used for very high gauge factor.	bonded	unbonded	semiconductor	both a and b
17. In unbonded strain gauge, the resistance wires of about ___________ diameter is used.	0.025mm	0.0025mm	0.25mm	25mm
18. The order of the instrument is __________ if displacement is considered as input	zero	first	second	third
19. The order of the instrument is __________ if force is considered as input	zero	first	second	third
20. The filament wire in bonded type is made in the form of	flat grid	flat helix	thin foil	all the above
21. In flat grid gauge lengths were around _________	2.5cm	25cm	2.5mm	25mm
22. In flat helix gauge lengths were upto _________	0.15cm	0.015cm	0.1cm	0.15mm
23. In foil grid type, gauge lengths were about_________	1mm	0.5mm	1.5mm	2mm
24. For the measurement of strain above 250° C ____________ is suitable.	Nichrome V	Isoelastic	Advance	both b and c
25. The base carrier material for filament wire are	impregnated paper	phenolic plastic	phenolic plastic	all the above
26. Temperature compensation in strain gauge is obtained by using ________ identical to the active gauge	dummy gauge	pirani gauge	thermal conductivity gauge	ionization gauge
27.The gauge factor for semiconductor strain gauge is mainly contributed by ________	area	length	piezoresistive effct	all the above
28. If the conductor or metal are used to measure the temperature, they are known as	resistance thermometer	*thermistor*	anemometer	all the above
29. If the semi conductor are used to measure the temperature, they are known as	resistance thermometer	thermistor	anemometer	all the above
30. The conductive elements used in resistance thermometer are	nickel	copper	tungton	all the above
31.For measuring surface temperature _________ is used.	platinum RTD	wafer type resistance bulb	nickel RTD	all the above
32. The choice of elements for the resistance thermometer for the temperature range of 250 to 1000^0 C is	Platinum	Copper	Nickel	Tungten
33. The choice of elements for the resistance thermometer for the temperature range of 160 to 2600^0 C is	Platinum	Copper	Nickel	Tungten
35. The choice of elements for the resistance thermometer for the temperature range of 250 to 1100^0 C is	Platinum	Copper	Nickel	Tungten
36. ----------------- are used to measure the velocity of flow	Potentiometer	Anemometer	Strain gauge	Thermometer
37. ----------------- are used to measure the temperature	potentiometer	Anemometer	Strain gauge	Thermometer
38. Hot wire anemometer are classified into ------------ categories	2	3	4	4
39. The Gauge factor of Nichrome is	2	3	4	5
40. The Gauge factor of Iridium – Platinum is	2.1	5.1	4.1	1.1
41. The Gauge factor of Nickel is	-12	-3	-4	-54
42. The Gauge factor of Manganin is	0.57	0.67	0.47	0.77
43. The lead wire insulation material for temperature below 75^{0}C is	Nylon	Vinyl	Polyethhylene	Teflon
44. The lead wire insulation material for temperature between 75^{0}C to 65^{0}C is	Nylon	Vinyl	Polyethhylene	Teflon
45. The lead wire insulation material for temperature between 75^{0}C to 95^{0}C is	Nylon	Vinyl	Polyethhylene	Teflon
46. The lead wire insulation material for temperature between 75^{0}C to 260^{0}C is	Nylon	Vinyl	Polyethhylene	Teflon
47. In a resistance potentiometer, the non-linearity is	Increases with increase	Decreases with increase	It is not dependent upo	None of the above
48. The Gauge factor is affected by --------------- factors	2	4	3	Many
49. The base carrier material used in strain gauge should be	Poor	Good	Very poor	Moderate
50 . The frequency response up to to 17000 cps when the av	10 m / s	30 m / s	90 m / s	9 m / s
51 . The frequency response up to to 30000 cps when the av	10 m / s	30 m / s	90 m / s	9 m / s
52 . The frequency response up to to 50000 cps when the av	10m/s	30 m / s	90 m / s	9 m / s
53. In a resistance potentiometer high value of resistance of	Low value of sensitivit	High value of sensitivity	Low value of Non-linea	Low value of error

54. An unbonded strain gauges are	Exclusively used for tra	Exclusively used for Stre	Commonly used for bo	None of the above
55. The Wire wound starin gauge the approximate value of g	1 + 2 Δs / s	1 + 2 ΔR / R	1 + 2 v	1 + 2 ΔD/ D
56. Platinum is the commonly used metal for RTD because	Platinum has a constan temperature range between 0 – 100^0C	The resistivity of platinu	Platinum is available ir	All the above
57. The base carrier material used in strain gauge should be	poor	Good	Very poor	Moderate

UNIT IV

QUESTIONS	OPT1	OPT2	OPT3	OPT4
1.The transducer in which self inductance or the mutual inductance of a couple of coils is changed when the input is varied is	Resistance transducer	Inductance transducer	Capacitance transducer	All the above
2.Inductance of a coil can be described in terms of	no of turns	permeability of material	geometric factor	All the above
3.LVDT works on the principle of	self inductance	mutual inductance	both a and b	none of the above
4.The secondary windings have ___________ no of turns	equal	unequal	half of other	none of the above
5. The frequency of a.c applied to primary windings may be between	50 HZ to 20 KHZ	50 HZ to 20HZ	100HZ	50KHZ
6.When the soft iron core is in null position, the emf induced in secondary windings S1 and S2 is ___________	ES1=ES2	ES1<ES2	ES1>ES2	none of the above
7. When the soft iron core is moved to left of null position, the emf induced in secondary windings is ___________	ES1=ES2	ES1<ES2	ES1>ES2	none of the above
8. When the soft iron core is moved to right of null position, the emf induced in secondary windings is ___________	ES1=ES2	ES1<ES2	ES1>ES2	none of the above
9. The output curve of LVDT is linear upto _____________ of displacement	6mm	10mm	5mm	2mm
10.At null position the output voltage is	zero	positive	negative	not defined
11.When the core is moved left (ie) nearer S1, the output voltage is	zero	positive	negative	not defined
12. When the core is moved right(ie) nearer S2, the output voltage is	zero	positive	negative	not defined
13. When the core is moved left (ie) nearer S1, the phase angle is	φ = 0º	φ = 90º	φ = 180º	φ = 360º
14. When the core is moved right (ie) nearer S2, the phase angle is	φ = 0º	φ = 90º	φ = 180º	φ = 360º
15.The range of LVDT measurement of displacement is	1.25mm to 250mm	1.5mm to 200mm	1.25m to 200m	200mm
16. LVDT is _______________ device	high friction	frictionless	less friction	none of the above
17.Application of LVDT	aircrafts	missiles	space vehicles	All the above
18.LVDT has high sensitivity of about	30 V/mm	40 V/mm	50 V/mm	100 V/mm
19.LVDT is _____________ power consumption device	high	low	very high	very low
20.LVDT is used for measurement of	displacement	tension in a cord	force, pressure	All the above
21.Induction potentiometer has _________ windings	one	two	three	many
22.The distribution of rotor and stator windings provide linear relation upto	±90º	±180º	±270º	All the above
23.The variable reluctance accelerometer for measurement of acceleration has the range of	±2g	±4g	±5g	±7g
24. When the acceleration of +4g was applied, the output obtained is	10V	5V	0V	negative voltage
25. When the acceleration of -4g was applied, the output obtained is	10V	5V	0V	negative voltage
26.The residual voltage in the LVDT is due to	harmonics in input	interruption in input	both a and b	none of the above
27.The transducer in which capacitance changes when the input is varied is	Resistance transducer	Inductance transducer	Capacitance transducer	All the above
28.In Capacitive transducer, the change in capacitance is caused by	change in overlapping area	change in distance between plates	change in dielectric constant	All the above
29.The capacitance changes _________ with change in area of plates	linear	nonlinear	independent	none of the above
30.The Capacitance of parallel plate capacitor is	C= εd/A	C= εA/d	C= εA/d2	C= ε /d
31.The Capacitive transducer with parallel plate capacitor is suitable for measurement of linear displacement ranging from	1m to 10 m	1mm to 10mm	1 mm to 10mm	upto 15mm
32.The capacitance is __________when the two plates completely overlap each other	maximum	minimum	zero	none of the above
33.The capacitance of the system _________ distance between plate increases	increases	decreases	independent	zero
34.The sensitivity of the capacitive transducer can be increased by making the distance between the plates __________	large	small	constant	very large

35. The Capacitance transducer can be used for measurement of	linear displacement	angular displacement	both a and b	none of the above
36.The capacitive transducer with differential arrangement has ________fixed plates & ________movable plate	2,1	1,2	2,2	3,1
37. The capacitive transducer with differential arrangement can be used for measurement of displacement in the range of	10-8 mm to 10 mm	1mm to 10 mm	> 15mm	< 1mm
38.Capacitive transducer using the principle of change of capacitance with change of dielectric are normally used for mm of	solid level	liquid level	gas levels	All the above
39.The transfer function of capacitive transducer is	$K / 1+ \tau s$	$K\tau / 1+ \tau s$	$K\tau s / 1+ \tau s$	$Ks / 1+ \tau s$
40.The phase shift of capacitance transducer is	$\varphi = 0$	$\varphi = \pi/2$	$\varphi = \pi/2 - \tan\text{-}1\ \omega\tau$	none of the above
41.The force requirement of capacitive transducer is _______and therefore they require __________power to operate them	small,less	large,high	small,high	large,less
42.__________transducers is used for measurement of humidity in gas	resistive	inductive	capacitive	All the above
43.Air cored inductive transducers are suitable for use	at lower frequencies	at higher frequencies	at equal frequencies	as iron core transducers
44.The size of air cored transducers as compared with their iron core counter part is	smaller	bigger	same	All the above
45.Inductive transducer are used in differential configuration because the output is not influenced by	external magnetic fields	temperature changes	variations of supply voltage & frequency	All the above
46. Capacitive transducers are normally used for	static measurement	dynamic measurement	both static & dynamic measurement	transient measurement
47.The dynamic characteristics of Capacitive transducer are similar to those of	low pass filter	high pass filter	notch filter	band stop filter
48.The nonlinear response of Capacitive transducer can be made linear by	differential arrangement	use of an OPAMP	working them over a small displacement range	All the above
49.An LVDT	exhibit linear characteristics upto displacement of ±5mm	has a linearity of 0.05%	has an infinite resolution	All the above
50.In a LVDT core is made up of a	non magnetic material	ferro electric material	nickel iron hydrogen annealed material	All the above
51.For the measurement of liquid level the dielectric used is	conducting liquid	non conducting liquid	either a or b	none of the above
52. Capacitance transducer is temperature _____________	sensitive	insensitive	based on dielectric either a or b	none of the above
53. Capacitive transducer cannot be used particularly for __________ measurements	static	dynamic	both a and b	transient
54. Capacitance transducer for measurement of pressure is based on change in	area	distance between plates	dielectric constant	All the above
55.Quartz diaphragms is used in Capacitive transducer because it has	low mechanical hysterisis	high mechanical hysterisis	high temperature coefficient	none of the above
56.For a cylindrical capacitor, the capacitance is	$C= 2\pi\varepsilon x/ \log(D2/D1)$	$C= 2\pi\varepsilon x/ \log(D/$	$C= 2\pi x/ \log(D2/D1)$	$C= 2\pi\varepsilon/ \log(D2/D1)$
57.The separation between LVDT core and LVDT coils permits the	isolation of media	long life	frictionless device	All the above
58.The primary winding in the circuit is always provided with	ac source	dc source	both a and b	none of the above
59.The core in the LVDT is made up of material with	high permeability	low permeability	either a or b	none of the above
60. __________transducers is used for measurement of humidity in gas	resistive	inductive	capacitive	All the above

UNIT V

QUESTIONS	OPTION A	OPTION B	OPTION C	OPTION D
Polarization occurs due to	rapid dissolving of magnesium in dilute acid	slow dissolving of magnesium in conc. Acid	copper electrode gets covered with bubbles of hydrogen gas	copper electrode gets covered with bubbles of oxygen gas
In a dry cell, polarization	cannot be prevented	is prevented through ammonium nitrate mixture	is prevented through magnese oxide	is prevented through a NaOH mixture
In electrochemical cell movement of ions is inhibited by a	salt bridge	electrode	solution	all of them
Conventionally, electrode potential refers to	oxidation	reduction	neutralization	charge potential
In non-metals, half cells electricity is conducted via solution by	platinum wire	platinum foil	both A and B	none
Standard electrode potential for any half-cell is measurement of	voltage	ions apart	radii of ions	deposited ions
Which of the following cannot be used as secondary reference electrode?	Calomel electrode	Silver-silver chloride electrode	Mercury-mercury sulphate electrode	Glass electrode
Which of the following is known as calomel?	Silver chloride	Mercury chloride	Potassium chloride	Mercury sulphate

The biocatalytic membrane is attached to the glass electrode using which of the following materials?	Nylon mesh	Teflon	Silicon rubber	Polythene
Biocatalytic membrane electrode cannot be used for the measurement of which of the following gases?	Ammonia	Carbon dioxide	Hydrogen	Nitrogen
Which of the following gas permeable membrane is used for ammonia gas sensing electrode?	Silicon rubber	Microporous Teflon membrane	Fluorocarbon	Polythene
Which of the following gas permeable membrane is used for carbon dioxide gas sensing electrode?	Silicon rubber	PVC membrane	Fluorocarbon	Polythene
Which of the following is not the characteristic of a reference electrode?	It must have a known output potential	It must have a constant output potential	Its output potential is dependent on the composition of the solution	It is employed in conjunction with the indicator or working electrode
Why is Standard hydrogen electrode called as the primary reference electrode?	It has a known output potential	It has a constant output potential	Its output potential is independent of the composition of the solution	Its output potential is zero volts
Which of the following is the simple and most convenient hydrogen electrode?	Pascal Hydrogen electrode	Bourne Hydrogen electrode	Hilderbant Hydrogen electrode	West Hydrogen electrode
More negative electrons (e^-) are attracted by more	positive pole	cathode	negative pole	anode
Negative electrode in half cell is made up of	hydrogen	zinc	copper	tungsten
It is easier to reduce ion on left if electrode is	more positive	less negative	both A and B	neutral
In carbon dioxide electrode, the membrane separates which of the following?	Sodium carbonate, magnesium chloride	Magnesium hydrogen carbonate, sodium chloride	Sodium hydrogen carbonate, sodium chloride	Magnesium carbonate, magnesium chloride
The biocatalytic membrane used in ammonia selective electrode is which of the following?	Urea	Urease	Acrylamide	Polyacrylamide
Which of the following is not the disadvantage of hydrogen electrode?	Platinum can be easily poisoned	Presence of oxidising agents alters the potential	It gives salt error	H2 gas at 1 atmospheric pressure is difficult to set up and transport
In Hydrogen electrode, the electrode is placed in a solution of ____ M Hcl. Fill in the blank.	0.5	1	2	3
Pure copper (Cu) rod in a solution of copper(II) sulfate ($CuSO_4$) solution constitutes the	half cell	electrode	ions	all of them
Ordinary dry cells are used in	toys	torches	both A and B	car
Half cells contain two ions of same element with different	atomic mass	oxidation state	nucleon number	electronic configuration
1 mole of Cl_2 requires electricity of	2 faraday	1 faraday	4 faraday	3 faraday
Hydrogen electrode which is the reference electrode can be used as which of the following?	Anode only	Cathode only	Anode or Cathode	Salt bridge
The composition of glass membrane in glass electrode cannot have which of the following?	Sodium silicate	Calcium silicate	Lithium silicate	Barium silicate
Cells with a size of button are used in	heart pacemakers	hearing aids	stomach ulcers	both A and B
Types of half cell includes	metal/metal ion	non-metal/non-metal	ion/ion	all of them
Composition of a standard hydrogen electrode is	hydrogen gas	H+ ions	platinum electrode	all of them
Species with higher oxidation are always written in an equation on	left hand side	right hand side	middle	nowhere
In non-metals, half cells electricity is conducted via solution by	platinum wire	platinum foil	both A and B	aluminum foil
Part of platinum electrode in a reaction is	more	less	neutral	often
Nickel cadmium cells are	smaller	low voltage supplier	high voltage supplier	a and c
Ions discharged in electrolysis depends on	relative electrode potential	concentration of ions	relative electrode charge	density of electrolyte
Production of energy in fuel cell as compare to petrol engine is considerably	high	low	same	constant
Species gaining electrons will be reduced and act as	reducing agent	oxidizing agent	neutralizing agent	reagent
Electrochemical cell is achieved by connecting two	ions	electrodes	half cells	all of them
Half-cell which is used to refer different electrode is standard	carbon electrode	hydrogen electrode	copper electrode	zinc electrode
Number of specified particles in 1 mole is	Avogadro constant	L	Leonardo's number	both A and B
Cells with a size of button are used in	heart pacemakers	hearing aids	stomach ulcers	both A and B
1 faraday is equal to	96500°C	12700°C	987690°C	96000°C
Effect of high voltage needed to discharge OH^- ion is called	over voltage effect	hydroxyl effect	high effect	all of them
Flow of electrons (e^-) through external circuit in cars provides energy to	drive	ignite	combustion	all of them
In button cells, negative pole is made up of	zinc	lithium	both A and B	silver
Light weight batteries which produce high voltage are	nickel cadmium cells	aluminum air batteries	lead(II) sulfate batteries	lead(II) oxide batteries
Oxidation of chloride ions (Cl^-) to chlorine (Cl_2) is done by	nitric acid	acidified MnO^{-4}	sulfuric acid	acidified ClO_2^{-3}
Number of faradays required to discharge 1 mole of an ion is equal to charge on that ion is	Faraday's first law	Faraday's second law	Lenz's first law	Lenz's second law
It is easier to reduce ion on left if electrode is	more positive	less negative	both A and B	neutral
Half reaction occur in fuel cell of	oxygen	hydrogen	hydrogen -oxygen	nitrogen
A secondary cell used in car battery is composed of plates of	lead	lead oxide	lead sulfate	both A and B

More negative electrons (e^-) are attracted by more	positive pole	cathode	negative pole	anode
Negative electrode in half cell is made up of	hydrogen	zinc	copper	tungsten
In electrolysis of silver nitrate solution, silver is deposited at	anode	cathode	inert electrode	charged electrode
Half-cell which is used to refer different electrode is standard	carbon electrode	hydrogen electrode	copper electrode	zinc electrode
Faraday has proposed two laws of	electrolysis	hydrolysis	electromagnetism	gravity
When rate of gain of electrons will be equal to loss of electrons state obtained will be	Redox equilibrium	neutral	constant	unstable
Part of platinum electrode in a reaction is	more	less	neutral	often
In Hydrogen electrode, the electrode is placed in a solution of ____ M Hcl. Fill in the blank.	0.5	1	2	3

Answer

primary or secondary

standard meter

null & deflection
deflection method
null method
null method
all the above
transducer
null method
all the above

standard instrument and input source

constant, varied
3
Gross error

all the above

Systematic error

2

instrumental

environmental

static

dynamic
Random error

statistical method
all the above
arithmetic mean

deviation
variance

median

mode
Gaussian curve
Gaussian curve

all the above
± 0.6745s
limiting error
odds(odds+1) = probability of occurance

3

all the above
variation of resistance
variation of inductance
variation of capacitance
both a & b

elastic effect

all the above

2

passive

active
strain gauge
thermocouple
2

fundamental unit

derived unit
all the above
both a & c

6,2,many
candela

Paris
National standards laboratory
New Delhi
steradian
kilogram

Answer

Characteristics

2
static&dynamic

static

dynamic
linear differential equation

non-linear
all the above
all the above

senstivity

vary
output unit/ input unit
mm/ º C
angular degree/ kpa

linear

linearity

least square fit
minimum of sum of squares of deviation

Y= aX+b

all the above

Independant linearity
non damped

precision
precision&repeatability
accuracy
over damped

threshold

resolution

resolution

hysteresis

all the above

range

span

loading
input
impedance&stiffness

highest

3
all the above
1
K/ S
K/S^2
$Kw/S^2 + w^2$

y(t)= kr(t)

a_1 dy(t)/dt +a_0 y(t) =
b_0u(t)
a_2 d ^{2}y(t)/dt^2 +a_1
dy(t)/dt +a_0 y(t) =
b_0u(t)

Y(S)/ R(S)=K

Y(S)/U(S) = K/ τs +1

Y(S)/ R(S) = (b_0/ a_0)/
(a_2/ a_0 s^2+ a_1/ a_0 s +1)

potentiometer

theremocouple
vibration
galvanometer

Answer
R= ρl/a
all the above
350°

R_p/R_m

single slide wire

decreasing

75 to 150

all the above
vibration
all the above
unit resistance
0 and 0.5

both a and b

2

3.5

semiconductor

0.025mm

zero

first

all the above
2.5cm
0.15cm

1mm

Nichrome V
all the above

dummy gauge

piezoresistive effct
resistance
thermometer

thermistor

all the above
wafer type resistance
bulb

Platinum

Copper

Tungten

Anemometer

Thermometer

2
2
5.1
-12
0.47

Nylon

Vinyl

polyethylene

Polyethhylene
Decreases with
increase of load of
potentiometer
resistance
3
Good
9 m / s
30 m / s
90 m / s
High value of
sensitivity

Exclusively used for transducer applications
1 + 2 v
All the above

Good

ANSWERS

Inductance transducer

All the above
mutual inductance

equal

50 HZ to 20 KHZ

ES1=ES2

ES1>ES2

ES1<ES2

5mm
zero

positive

negative

φ = 0º

φ = 180º
1.25mm to 250mm
frictionless
All the above
40 V/mm

low
All the above
two

±90º

±4g

5V

0V
harmonics in input
Capacitance transducer

All the above

linear
C= εA/d

1 mm to 10mm

maximum

decreases

small

both a and b

2,1

10-8 mm to 10 mm

liquid level
$K\tau s / 1+ \tau s$
$\varphi = \pi/2 - \tan^{-1} \omega\tau$

small,less

capacitive

at higher frequencies

bigger

All the above
dynamic
measurement

high pass filter

All the above

All the above
nickel iron hydrogen
annealed material
non conducting
liquid

sensitive

static

dielectric constant
low mechanical
hysterisis

$C= 2\pi\varepsilon x/ \log(D2/D1)$

All the above

ac source
high permeability

capacitive

ANSWERS

copper electrode gets
covered with bubbles of
hydrogen gas

is prevented through
magnese oxide

salt bridge
reduction

both A and B

voltage

Glass electrode
Mercury chloride

Nylon mesh

Nitrogen

Fluorocarbon

Silicon rubber
Its output potential is dependent on the composition of the solution

Its output potential is zero volts
Hilderbant Hydrogen electrode
positive pole
zinc
both A and B
Magnesium hydrogen carbonate, sodium chloride

Urease

It gives salt error

1

half cell
both A and B

oxidation state
2 faraday

Anode or Cathode

Barium silicate
both A and B
all of them
all of them

middle

both A and B
less
a and c
relative electrode charge

high
oxidizing agent
half cells

hydrogen electrode
both A and B
both A and B
96500°C

over voltage effect

drive
both A and B

aluminum air batteries

acidified MnO^{-4}

Faraday's second law
both A and B
hydrogen -oxygen

both A and B

positive pole
zinc

cathode

hydrogen electrode
electrolysis

Redox equilibrium
less

1