Biomedical Instrumentation

Lecture 1

Instructor

Dr. M. Nabeel Anwar
Room no. 409
Phone 9085-6050
nabeel@smme.nust.edu.pk

Contact Hours:

Office: Whenever the door is unlocked or Human Systems Lab
Email: 24/7
Cell: Only for CR

Text Books

"Class Notes"
Webster. John G: Medical Instrumentation, 3rd edition, Wiley and Sons.

Exams Scoring:

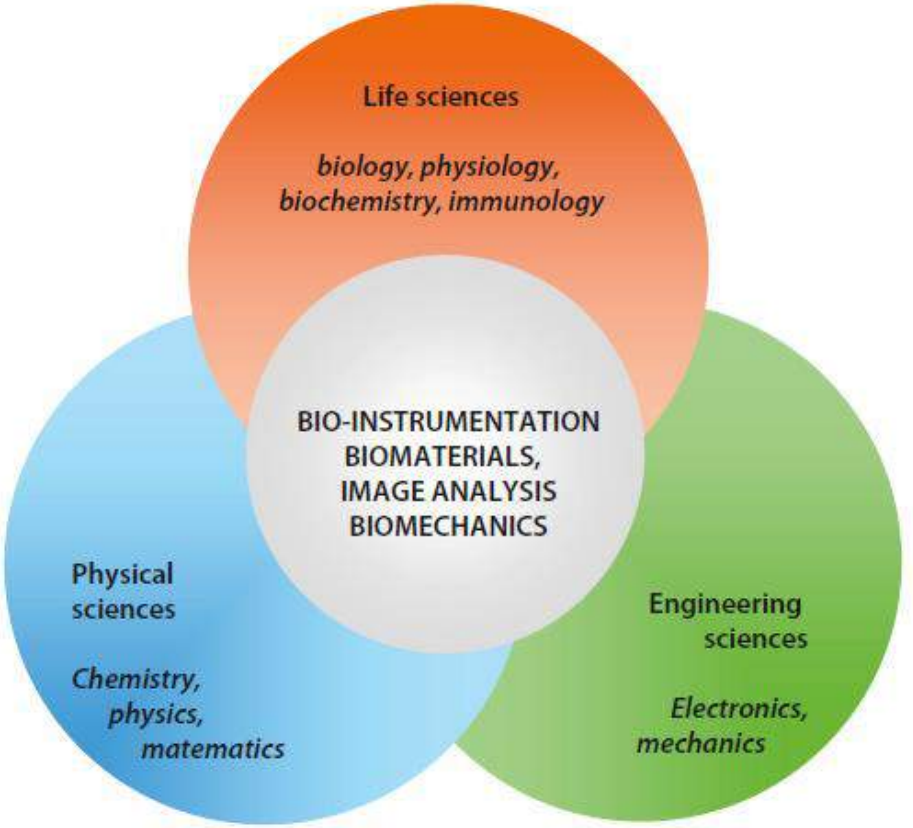
Quiz	10%
Assignments	15%
2xOHT	35%
Final	40%

Biomedical Engineering and Sciences

Highly interdisciplinary profession concerned with the application of

- engineering,
- Life sciences,
- computing, and
- allied science methodologies

in biological and physiological problems.



Biomedical Engineering and Sciences

"In Biomedical engineering and Sciences" we use

- advances knowledge in engineering, biology and medicine, and improves human health through cross-disciplinary activities. As a result it produces technological advances in health care.

It includes:

1. The acquisition of new knowledge and understanding of living systems through experimental and analytical techniques based on the engineering sciences.
2. The development of new devices, algorithms, processes and systems that improve medical practice and health care.

3. Design and manufacture products that can
   - monitor physiologic functions or
   - display anatomic detail

4. Detection, measurement, and monitoring of physiologic signals
   - biosensors
   - biomedical instrumentation
   - Medical imaging

5. Assist in the diagnosis and treatment of patients
   - Computer analysis of patient-related data
   - clinical decision making
   - medical informatics
   - artificial intelligence

6. supervise biomedical equipment maintenance technicians,
   - investigate medical equipment failure
   - advise hospitals about purchasing and installing new equipment

Some Branches of BMES…

Core Course

- **Biomechanics**
  - application of classical mechanics to biological or medical problems
  - study of movement of biologic solids, fluids and viscoelastic materials, muscle forces
  - design of artificial limbs

Elective Course

- **Biomaterials:**
  - study of both living tissue and artificial synthetic biomaterials (polymers, metals, ceramics, composites) used to replace part of a living system or to function in intimate contact with living tissue (implants)
  - biomaterials:
    - nontoxic,
    - non-carcinogenic
    - chemically inert
    - stable
    - mechanically strong

Some Branches of BMES…

- **Biomedical sensors**
  - physical measurements, biopotential electrodes, electrochemical sensors, optical sensors.

Elective course

- **Bioelectric phenomena:**
  - origin in nerve and muscle cells
  - generation in nerves, brain, heart, skeletal muscles
  - analysis,
  - modelling,
  - recording and
  - diagnosis

Elective course

Some Branches of BMES…

Core course

- **Biomedical signal processing and analysis**
  - collection and analysis of data from patients
  - bioelectric, physical, chemical signals
  - online (embedded) and off-line processing and analysis
- **Medical imaging and image processing:**
  - provision of graphic display of anatomic detail and physiological functions of the body
  - medical imaging methods and devices
    - physical phenomena + detectors + electronic data processing+ graphic display = image
    - x-ray, gamma photons, MRI, Ultrasound

Some Branches of BMES…

Core course

- **Medical instruments and devices:**
  - design of medical instruments and devices to monitor and measure biological functions
  - application of electronics and measurement techniques to develop devices used in diagnosis and treatment of disease
    - biopotential amplifiers
    - patient monitors
    - electrosurgical devices

Some Branches of BMES…

Elective courses

- **Cell and tissue engineering:**
  - utilization of anatomy, biochemistry and mechanics of cellular and subcellular structures to understand disease processes and to be able to intervene at very specific sites.
  - design, construction, modification, growth and maintenance of living tissue (bioartificial tissue and alteration of cell growth and function)

Elective courses

- **Rehabilitation engineering:**
  - application of science and technology to improve the quality of life for individuals with physical and cognitive impairments (handicaps)

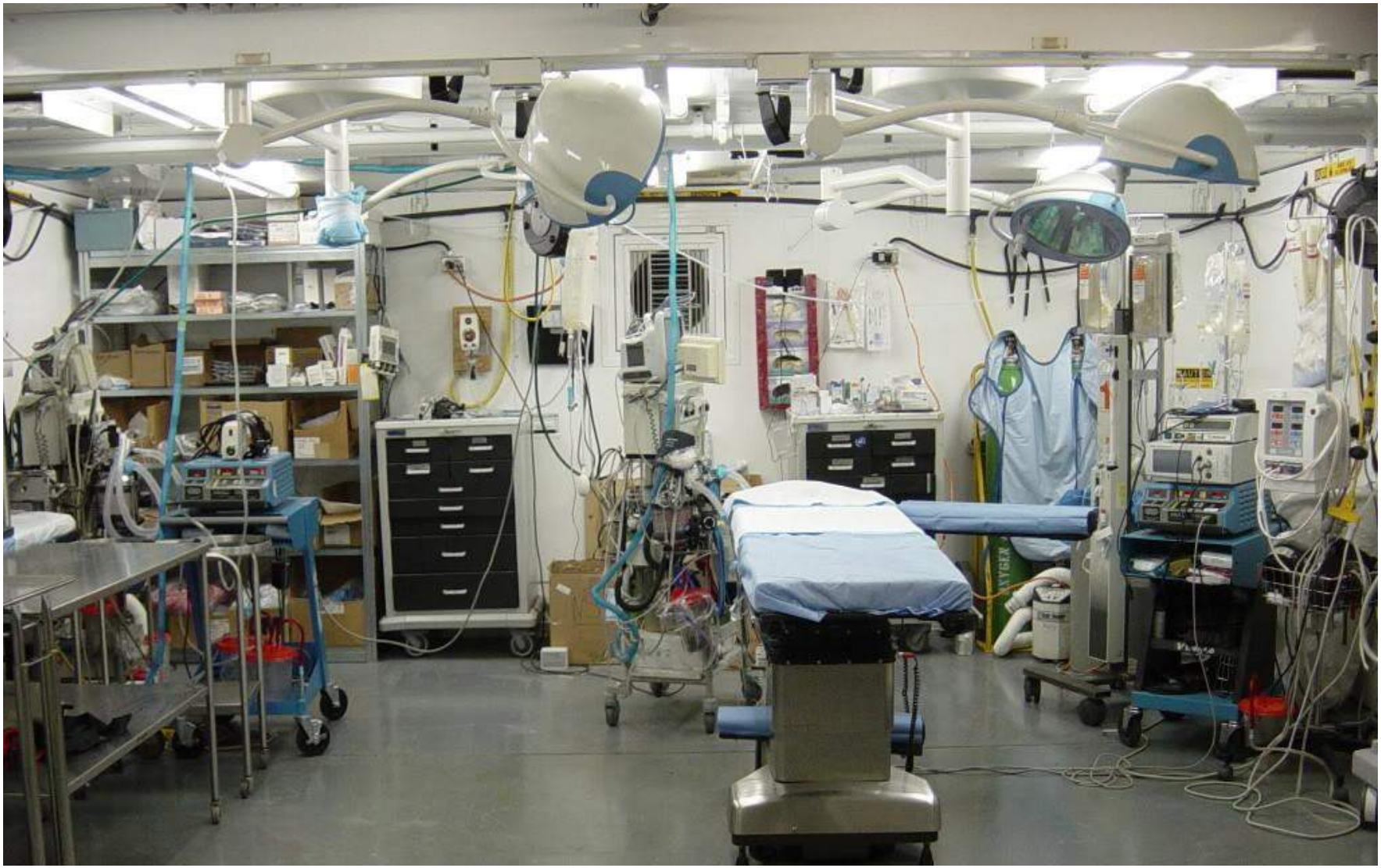
Some Branches of BMES…

- **Prostheses and artificial organs**
  - design and development of devices for replacement of damaged body parts
    - artificial heart,
    - circulatory assist devices,
    - cardiac valve prostheses,
    - artificial lung and blood-gas exchange devices,
    - artificial kidney, pancreas

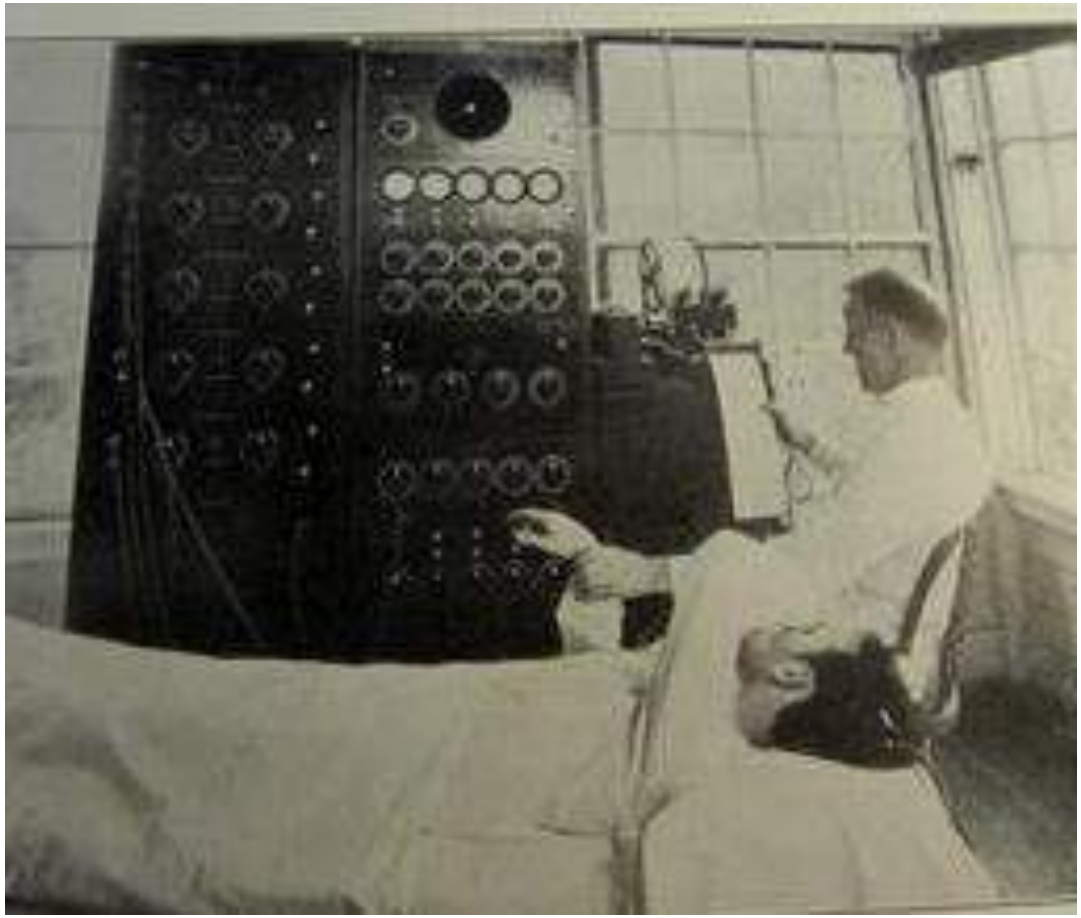
Some Branches of BMES…

- **Physiologic modelling, simulation and control**
  - use of computer simulation to help understand physiological relationships and organ function, to predict the behavior of a system of interests (human body, particular organs or organ systems and medical devices)
  - developing of theoretical (computational, analytical, conceptual etc) models

- **Medical informatics:**
  - hospital information systems, computer-based patient records, computer networks in hospitals, artificial knowledge-based medical decision making



Evolution of Medical Equipment



Earlier in 40’s

What is a Medical Device

Article 1(2) (a) MDD defines a medical device as:

"Any instrument, apparatus, appliance, software, material or other article, whether used alone or in combination, including the software intended by its manufacturer to be used specifically for diagnostic and/or therapeutic purposes and necessary for its proper application, intended by the manufacturer to be used for human beings for the purpose of:

- diagnosis, prevention, monitoring, treatment or alleviation of disease,
- diagnosis, monitoring, treatment, alleviation of or compensation for an injury or handicap,
- investigation, replacement or modification of the anatomy or of a physiological process,
- control of conception,

and which does not achieve its principal intended action in or on the human body by pharmacological, immunological or metabolic means, but which may be assisted in its function by such means."

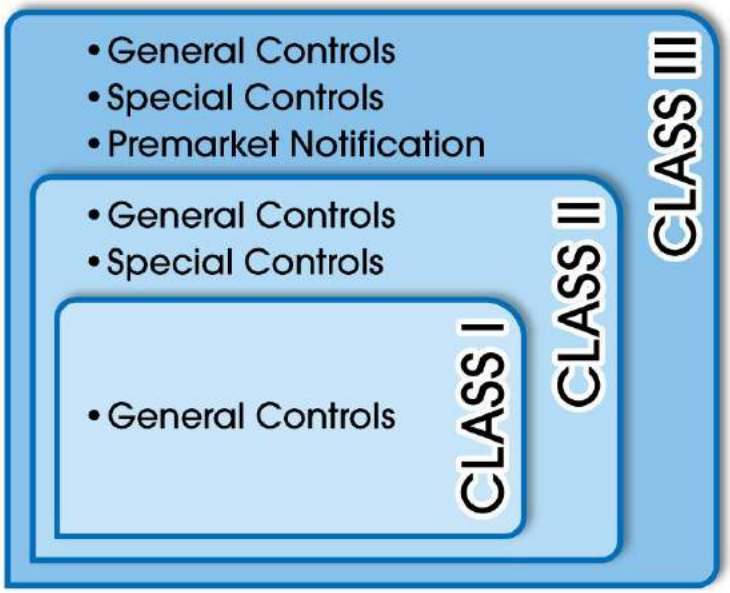
Medical device

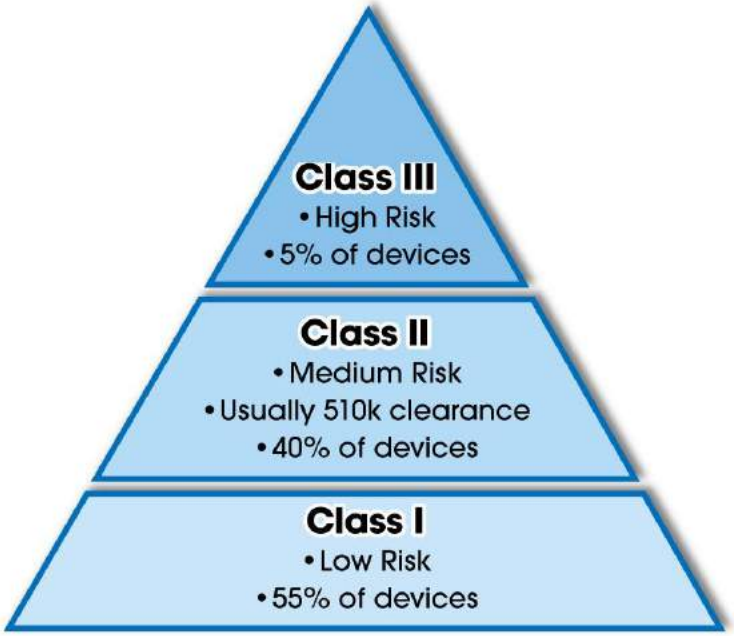
- Methods and devices are used to solve medical problems
  - problems are difficult, diverse, and complex
  - solution alternatives are limited and specific to a certain problem
- Therefore we must know
  - what we are measuring or studying
  - what we are treating
  - which methodologies are available and applicable

Medical device

- Requires body function’s deep understanding and analysis
- Interface between tissue and instrumentation is needed
- Procedures:
  - non-invasive
  - minimally invasive
  - invasive

Medical Device Classification





Medical devices are classified into Class I, II, and III. Regulatory control increases from Class I to Class III. The device classification regulation defines the regulatory requirements for a general device type. Most Class I devices are exempt from Premarket Notification 510(k); most Class II devices require Premarket Notification 510(k); and most Class III devices require Premarket Approval.

Source: FDA

Classification Examples

Class I	Class II	Class III
Stethoscopes	Catheters	Automatic Defibrillators
Tung Depressors	Dental Implants	Artificial Hip Joints
Reagents used in Clinical Labs	Biopsy Needles	Heart Valves
Powered Tooth Brushes	Ultrasound Imaging System	Extended Wear Contact Lenses
Dental Chair	Powered Wheelchair	Left Ventricular Assist Devices

Medical Device groups

Medical devices can be grouped according to the three areas of medicine:

Diagnosis

Diagnostic devices

Therapy

Therapeutic devices

Rehabilitation

Application of Assisting orthotic-prosthetic devices

Diagnostic devices

- Types of diagnostic devices
  - recording and monitoring devices
  - measurement and analysis devices
  - imaging devices
- Importance of diagnostic devices
  - enhance and extend the five human senses to improve to collect data from the patient for diagnosis
  - the perception of the physician can be improved by diagnostic instrumentation in many ways:
    - amplify human senses
    - place the observer's senses in inaccessible environments

Therapeutic devices

- Objective of therapeutic devices:
  - deliver physical substances to the body to treat disease
- Physical substances:
  - Voltage, current
  - Pressure
  - Flow
  - Force
  - Electromagnetic radiation
  - Heat
- Therapeutic device categories:
  - devices used to treat disorders
  - devices to assist or control the physiological functions

Assistive or rehabilitative devices

- Objective of rehabilitative devices
  - to assist individuals with a disability
- The disability can be connected to the troubles to
  - perform activities of daily living
  - limitations in mobility
  - communications disorders and
  - sensory disabilities
- Types of rehabilitative devices
  - Orthopedic devices
    - An orthopedic device is an appliance that aids an existing function
  - Prosthetic devices
    - A prosthesis provides a substitute

Problems Encountered in Measuring a Living System

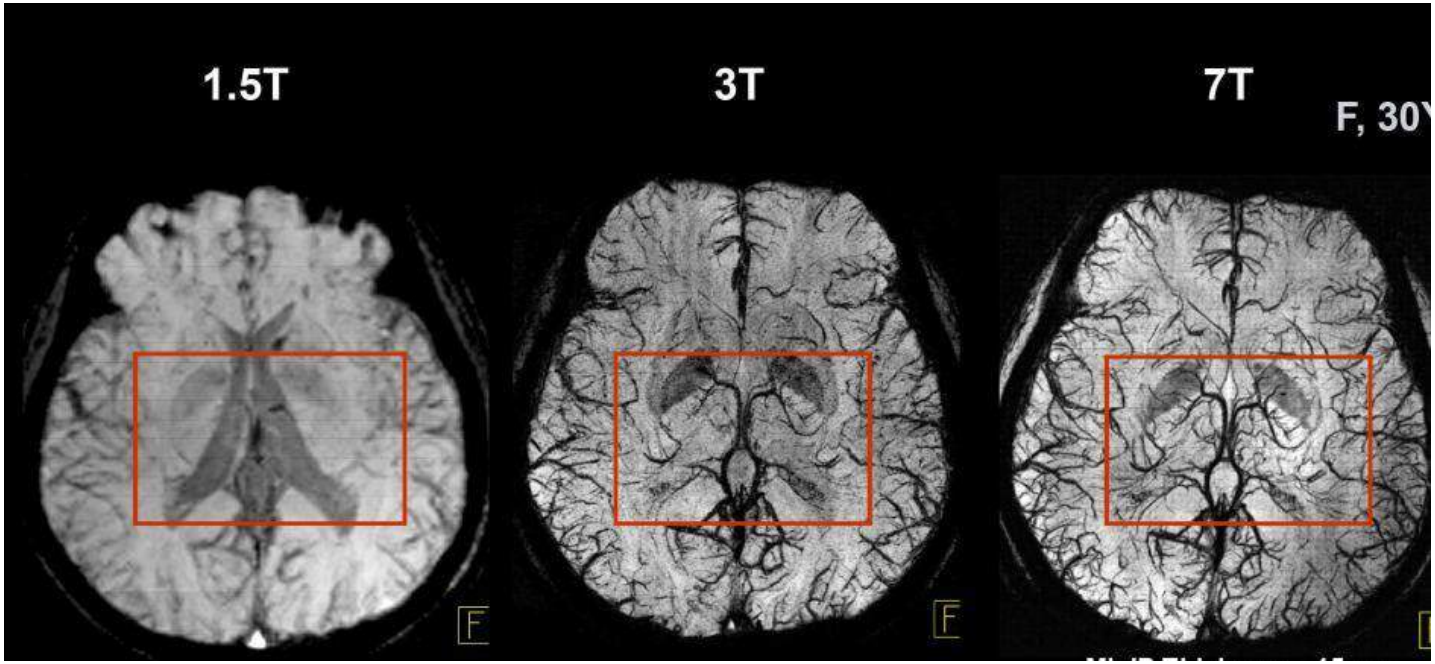
- Many crucial variables in living systems are inaccessible.
- Variables measured are seldom deterministic.
- Nearly all biomedical measurements depend on the energy.
- Operation of instruments in the medical environment imposes important additional constraints.

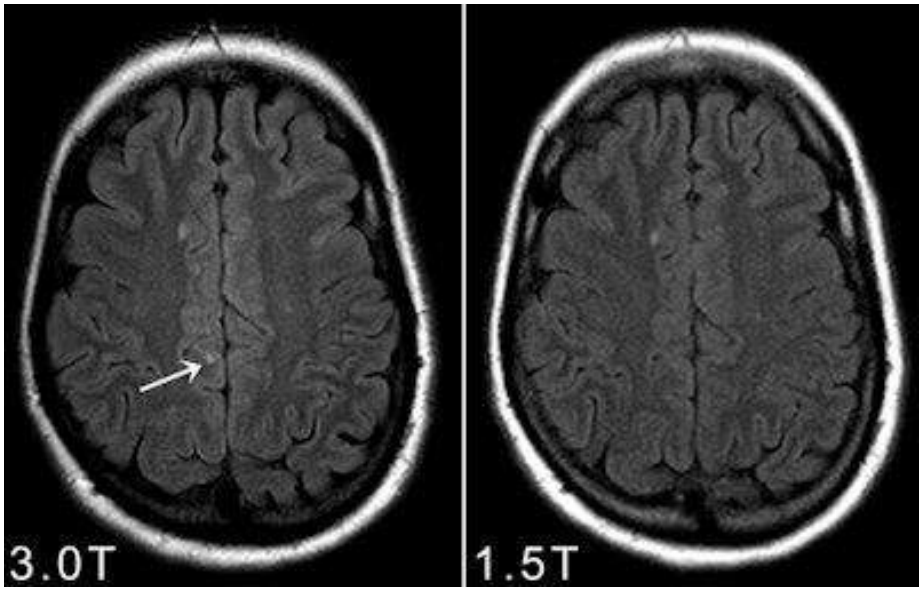
Biomedical Instrumentation

Importance: Diagnosis and therapy depend heavily on the use of medical instrumentation.

e.g.

1. Collection of data - qualitative and/or quantitative
2. Analysis of data
3. Decision making
4. Treatment planning based on the decision



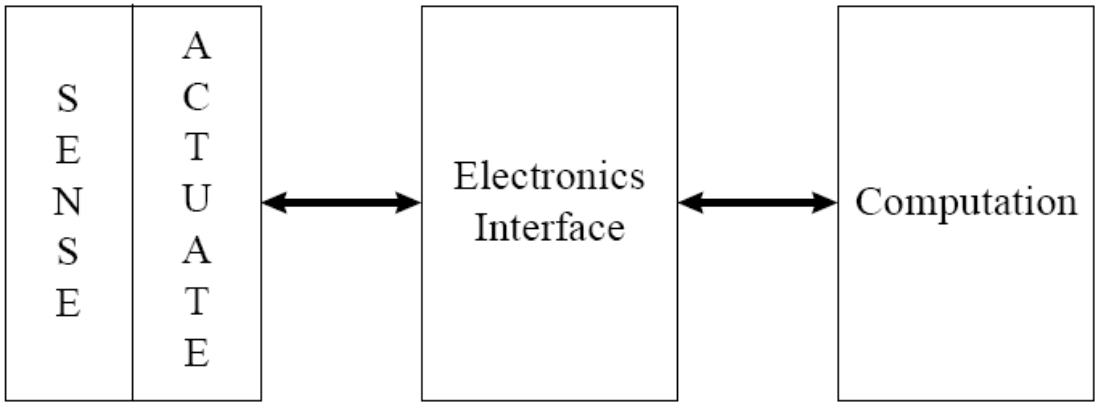


For Demonstration Purposes Only

Important Body signal measurements

Measurement	Range	Frequency, Hz	Method
Blood flow	1 to 300 mL/s	0 to 20	Electromagnetic or ultrasonic
Blood pressure	0 to 400 mmHg	0 to 50	Cuff or strain gage
Cardiac output	4 to 25 L/min	0 to 20	dye dilution
Electrocardiography	0.5 to 4 mV	0.05 to 150	Skin electrodes
Electroencephalography	5 to 300 μ V	0.5 to 150	Scalp electrodes
Electromyography	0.1 to 5 mV	0 to 10000	Needle electrodes
Electroretinography	0 to 900 μ V	0 to 50	Contact lens electrodes
pH	3 to 13 pH units	0 to 1	pH electrode
pCO_2	40 to 100 mmHg	0 to 2	pCO_2 electrode
pO_2	30 to 100 mmHg	0 to 2	pO_2 electrode
Pneumotachography	0 to 600 L/min	0 to 40	Pneumotachometer
Respiratory rate	2 to 50 breaths/min	0.1 to 10	Impedance
Temperature	32 to 40 °C	0 to 0.1	Thermistor

Biomedical Instrumentation System



All biomedical instruments must interface with biological materials. That interface can by direct contact or by indirect contact.

Components of Instrumentation System

- A sensor
  - Detects biochemical, bioelectrical, or biophysical parameters
  - Provides a safe interface with biological materials

Components of Instrumentation System

- An actuator
  - Delivers external agents via direct or indirect contact
  - Controls biochemical, bioelectrical, or biophysical parameters
  - Provides a safe interface with biologic materials

Components of Instrumentation System

The electronics interface

- Matches electrical characteristics of the sensor/actuator with computation unit
- Preserves signal to noise ratio of sensor
- Preserves efficiency
- Preserves bandwidth (i.e., time response) of sensor/actuator
- Provides a safe interface with the sensor/actuator
- Provides a safe interface with the computation unit

Components of Instrumentation System

The computation unit

- provides primary user interface
- provides primary control for the overall system
- provides data storage for the system
- provides primary signal processing functions for the system
- maintains safe operation of the overall system

Errors in measurements…

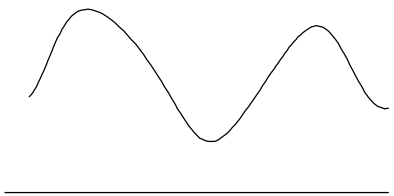
- When we measure a variable, we seek to determine the true value, as shown in Figure (next slide) .
- This true value may be corrupted by a variety of errors. For example
  - Movement of electrodes on the skin may cause an undesired added voltage called an artifact.
  - Electric and magnetic fields from the power lines may couple into the wires and cause an undesired added voltage called interference
  - Thermal voltages in the amplifier semiconductor junctions may cause an undesired added random voltage called noise. Temperature changes in the amplifier electronic components may cause undesired slow changes in voltage called drift.
- We must evaluate each of these error sources to determine their size and what we can do to minimize them.

Errors in measurements…

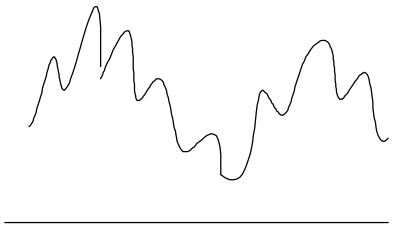
(a) Signals without noise are uncorrupted.

(b) Interference superimposed on signals causes error.

(a)



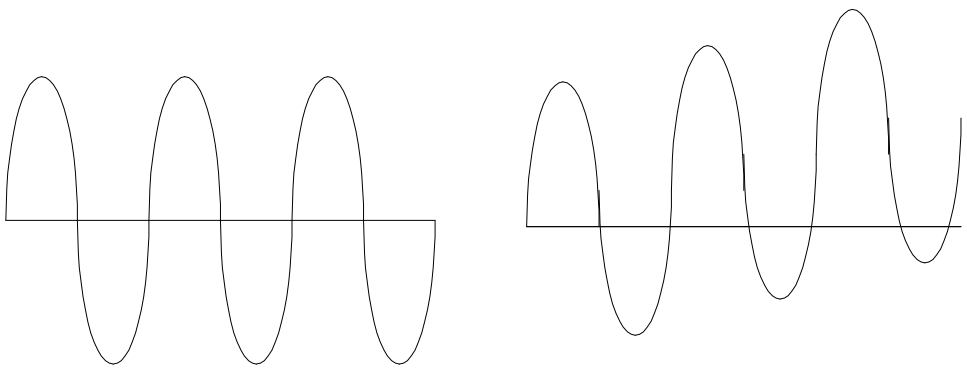
(b)



Errors in measurements…

(a)Original waveform.

(b) An interfering input may shift the baseline.



(a) (b)

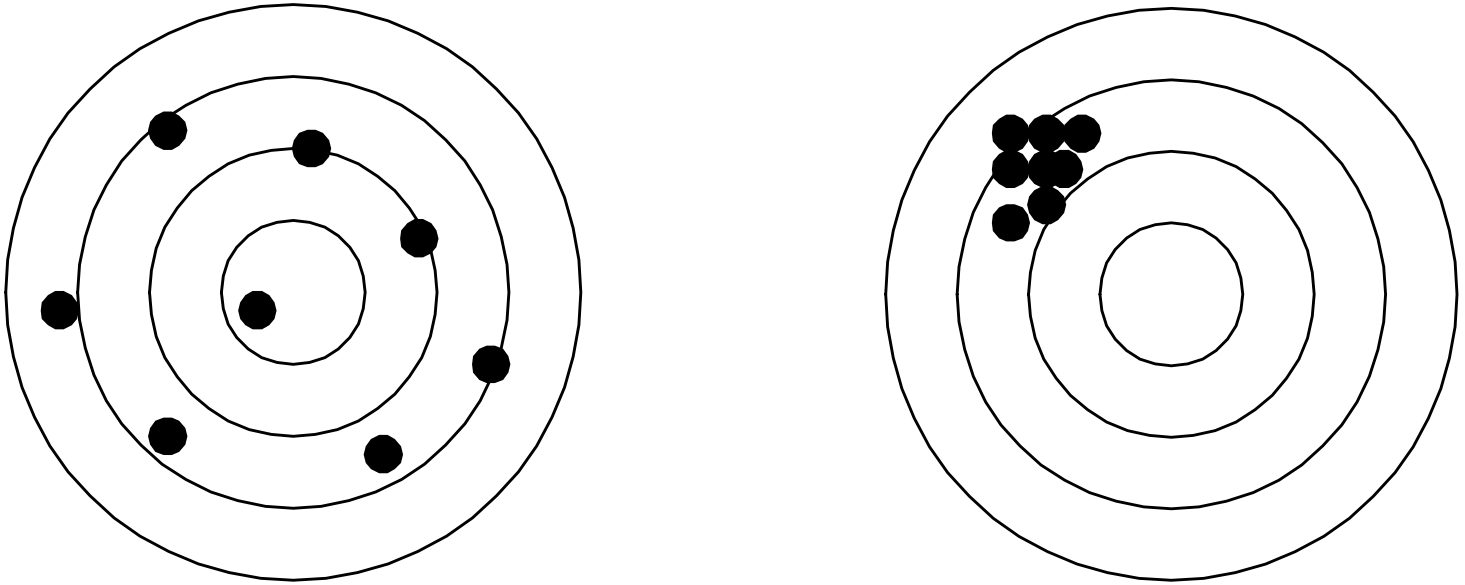
Errors in measurements: Accuracy and precision…

- Resolution
  - the smallest incremental quantity that can be reliably measured.
    - a voltmeter with a larger number of digits has a higher resolution than one with fewer digits.
  - However, high resolution does not imply high accuracy.
- Precision
  - the quality of obtaining the same output from repeated measurements from the same input under the same conditions.
  - High resolution implies high precision.
- Repeatability
  - the quality of obtaining the same output from repeated measurements from the same input over a period of time.

Errors in measurements: Accuracy and precision…

- Data points with

(a) low precision (b) high precision.



Errors in measurements: Accuracy and precision

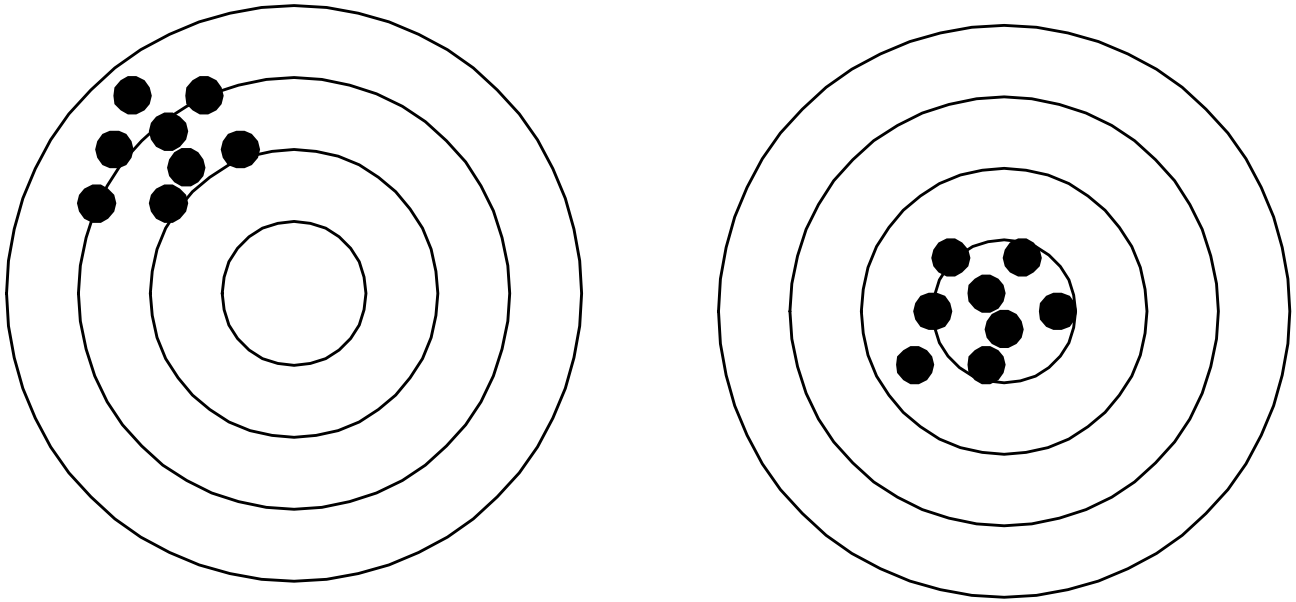
- Accuracy
  - the difference between the true value and the measured value divided by the true value.

- Obtaining the highest possible precision, repeatability, and accuracy is a major goal in bioinstrumentation design.

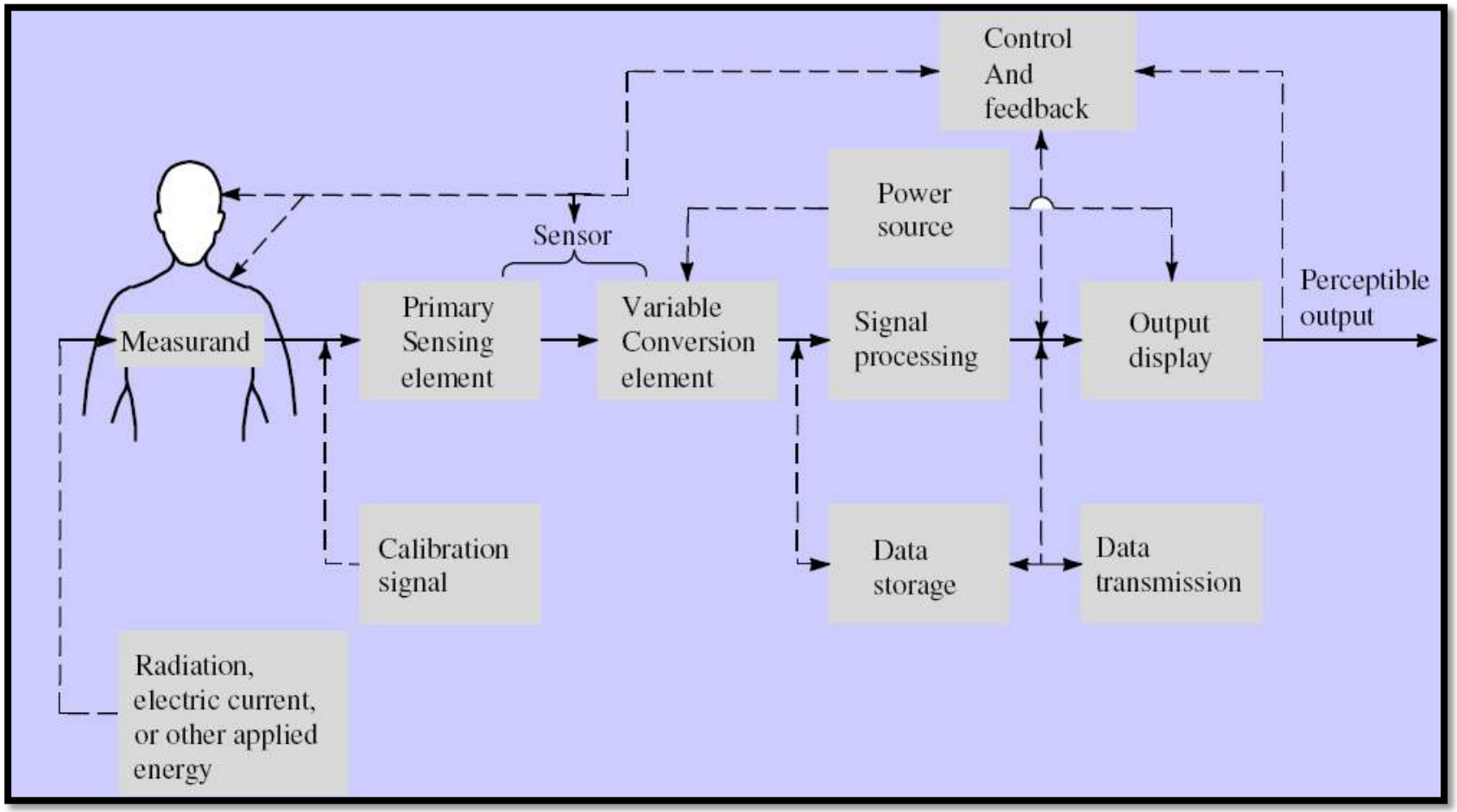
Errors in measurements: Accuracy and precision…

- Data points with

(a) low accuracy and (b) high accuracy



Generalized Medical Instrumentation System…



Generalized Medical Instrumentation System…

- Measurand
  - Physical quantity, property, or condition that the system measures
    - Biopotantial
    - Pressure
    - Flow
    - Dimension (imaging)
    - Displacement (velocity, acceleration, and force)
    - Impedance
    - Temperature
    - Chemical concentrations

Generalized Medical Instrumentation System…

- Sensor
  - Converts a physical measurand to an electrical output
    - Should respond only to the form of energy present in the measurand
    - Should be minimally invasive (ideally noninvasive)
- Signal conditioning
  - Amplify, filter, match the impedance of the sensor to the display
  - Convert analog signal to digital
  - Process the signal

Generalized Medical Instrumentation System…

- Output display
  - Results must be displayed in a form that the human operator can perceive
    - Numerical, Graphical, Discrete or continuous, Permanent or temporary, Visual or acoustical
- Auxiliary elements
  - Data storage
  - Data transmission
  - Control and feedback
  - Calibration signal

Example: The specifications for a typical blood pressure sensor

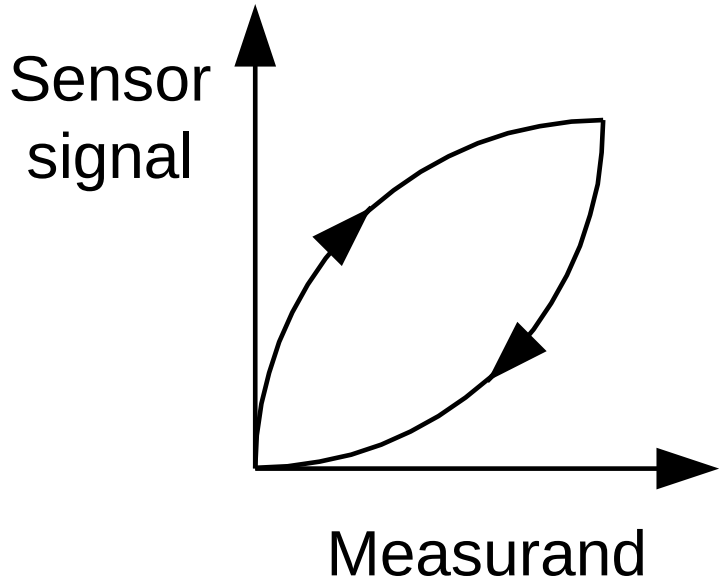
Sensor specifications for blood pressure sensors are determined by a committee composed of individuals from academia, industry, hospitals, and government

Specification	**Value**
Pressure range	–30 to +300 mmHg
Overpressure without damage	–400 to +4000 mmHg
Maximum unbalance	±75 mmHg
Linearity and hysteresis	± 2% of reading or ± 1 mmHg
Risk current at 120 V	10 μA
Defibrillator withstand	360 J into 50 Ω

Generalized Medical Instrumentation System…

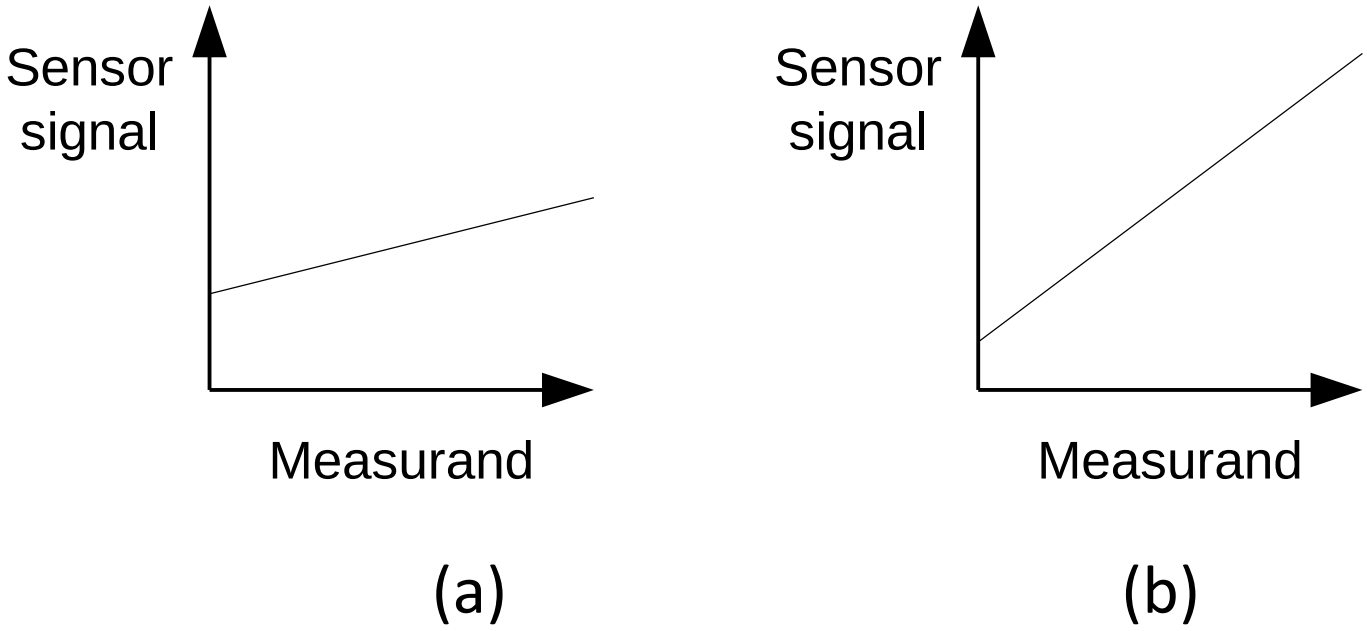
A hysteresis loop.

- The output curve obtained when increasing the measurand is different from the output obtained when decreasing the measurand.



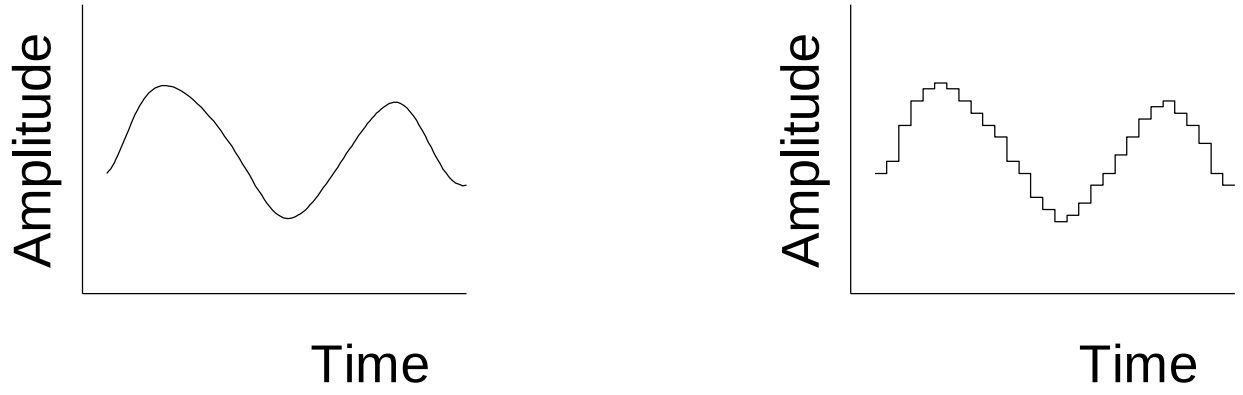
Generalized Medical Instrumentation System…

(a) A low-sensitivity sensor has low gain. (b) A high sensitivity sensor has high gain.



Generalized Medical Instrumentation System…

- Most sensors are analog and provide a continuous range of amplitude values for output (left fig).
- Other sensors yield the digital output (right fig).
  - Digital output has poorer resolution, but does not require conversion before being input to digital computers and is more immune to interference

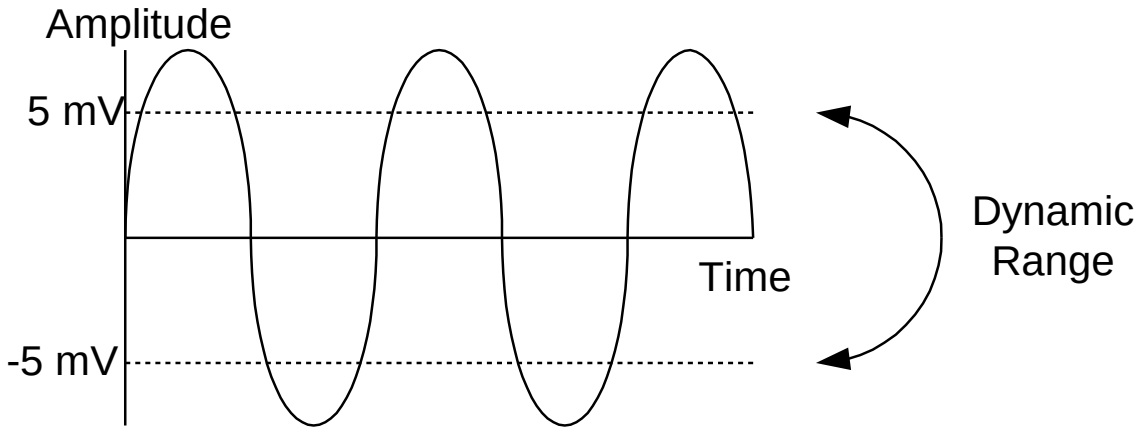


- Bioinstruments should be designed with a specific signal in mind.
  - Table shows a few specifications for an electrocardiograph
  - The values of the specifications, which have been agreed upon by a committee, are drawn from research, hospitals, industry, and government.

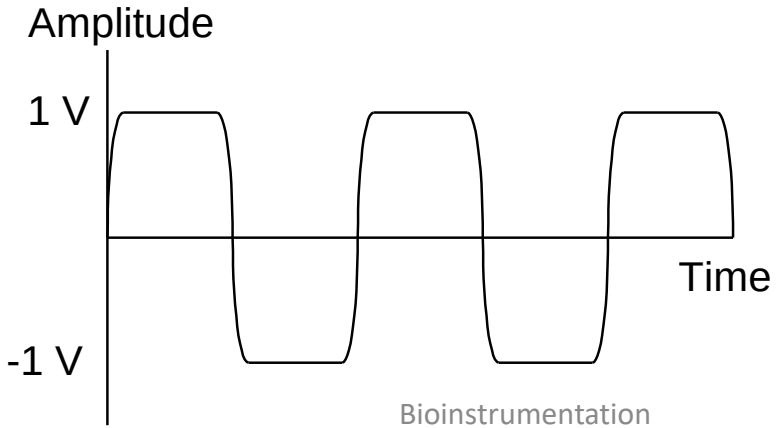
Specification	**Value**
Input signal dynamic range	±5 mV
Dc offset voltage	±300 mV
Slew rate	320 mV/s
Frequency response	0.05 to 150 Hz
Input impedance at 10 Hz	2.5 MΩ
Dc lead current	0.1 μA
Return time after lead switch	1 s
Overload voltage without damage	5000 V
Risk current at 120 V	10 μA

(a) An input signal which exceeds the dynamic range.
(b) The resulting amplified signal is saturated at ±1 V.

(a)



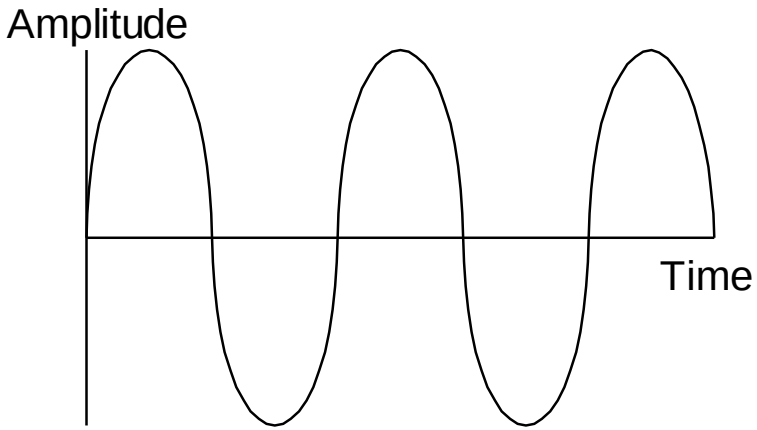
(b)



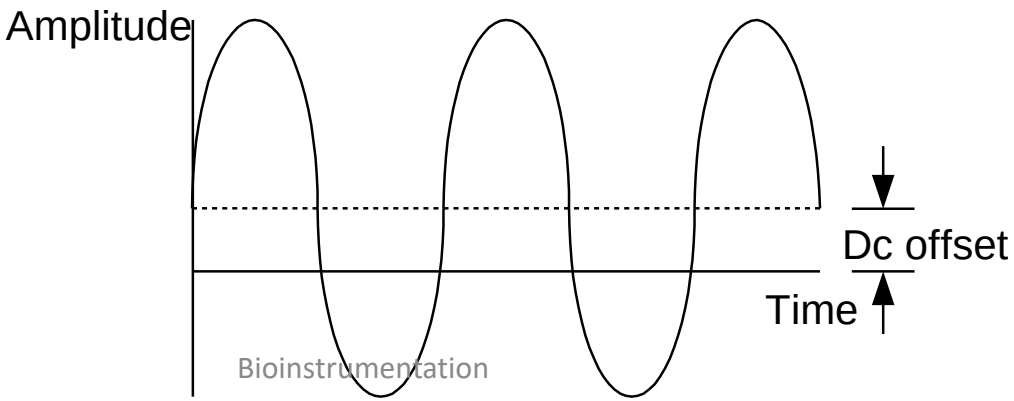
Generalized Medical Instrumentation System…

DC offset voltage is the amount a signal may be moved from its baseline and still be amplified properly by the system. Figure shows an input signal without (a) and with (b) offset.

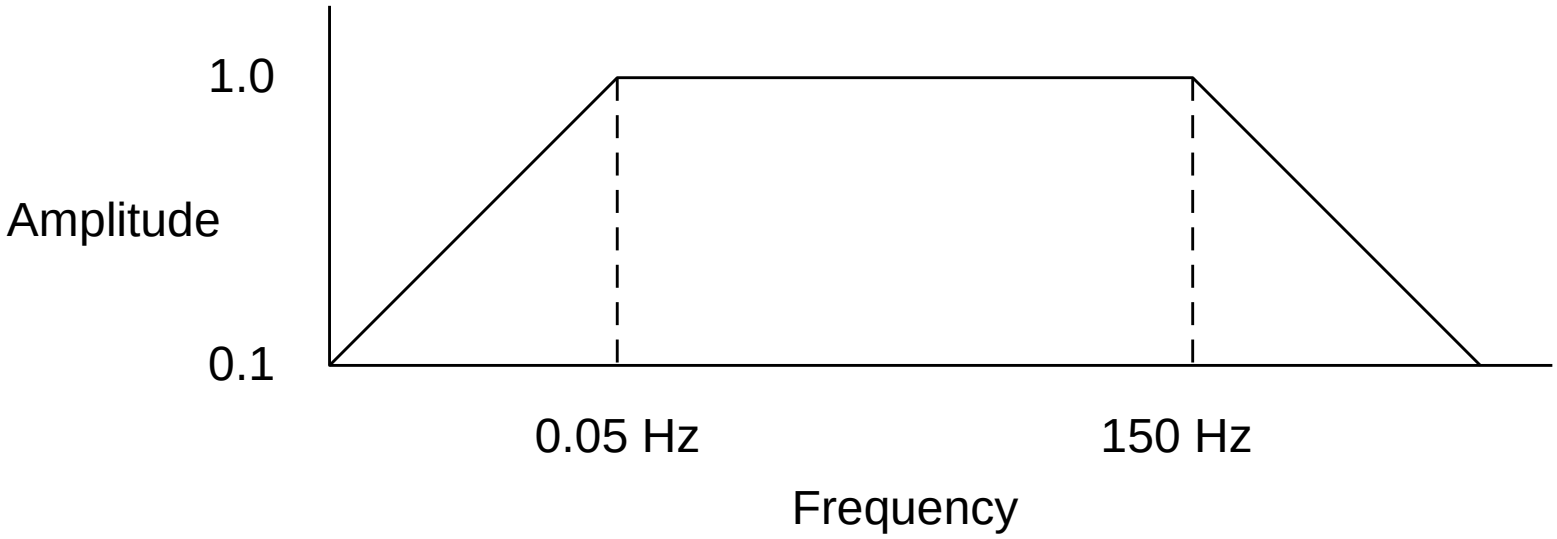
(a)



(b)

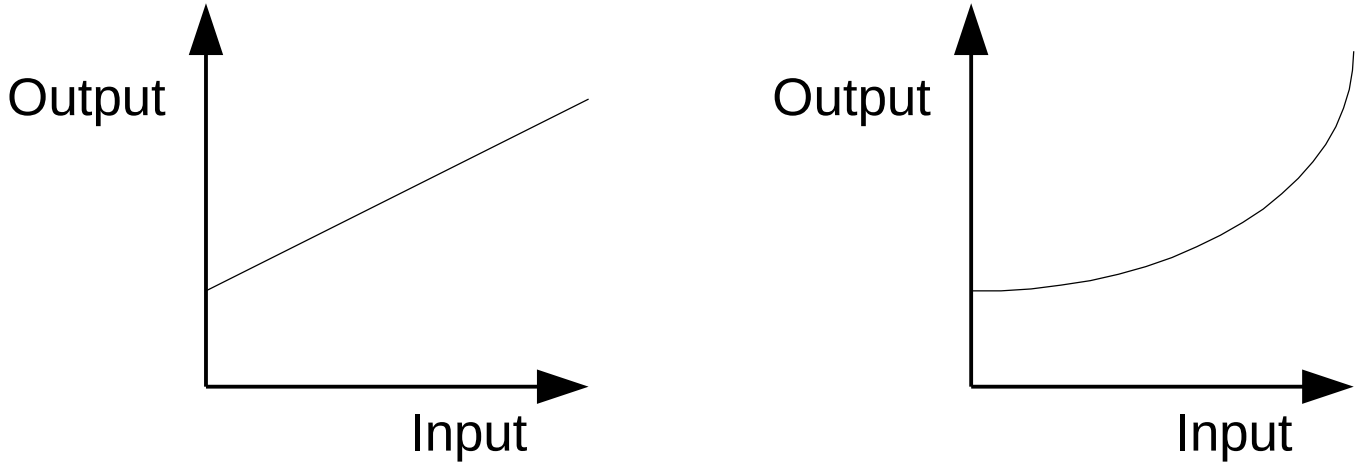


- The frequency response of a device is the range of frequencies of a measurand that it can handle.
- Frequency response is usually plotted as gain versus frequency.
- Figure shows Frequency response of the electrocardiograph.

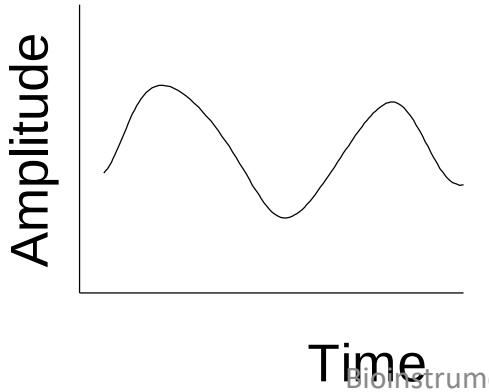


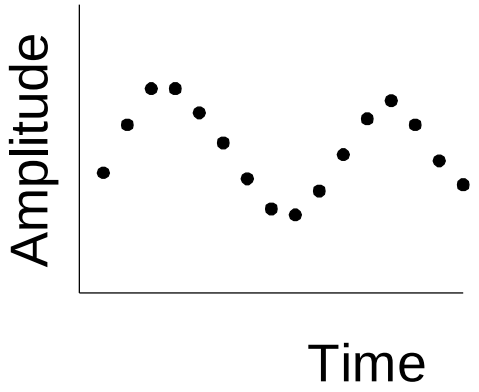
- Linearity is highly desirable for simplifying signal processing

- A linear system fits the equation y = mx + b.
- (b) A nonlinear system does not fit a straight line.



- All bioinstrumentation observes the measurand either continuously or periodically.
- However, computer-based systems require periodic measurements since by their nature, computers can only accept discrete numbers at discrete intervals of time.
- (a) Continuous signals have values at every instant of time.
- (b) Discrete-time signals are sampled periodically and do not provide values between these sampling times.





Calibration…

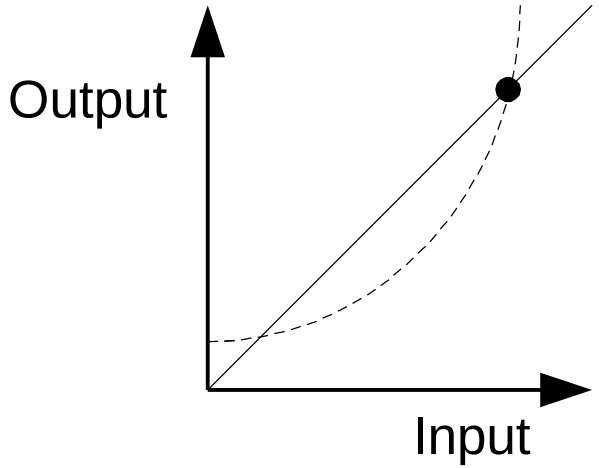
- Measuring instruments should be calibrated against a standard that has an accuracy 3 to 10 times better than the desired calibration accuracy.
- The accuracy of the standard should be traceable to the institutions regulating the standards (National Institute of Standards and Technology, TSI, etc.) .

Calibration…

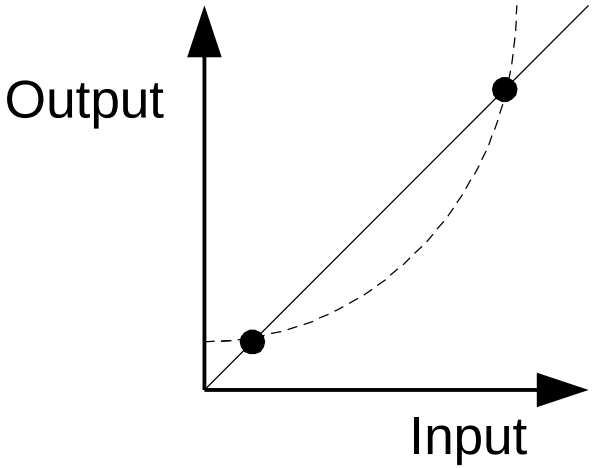
- If the instrument is linear,
  - its output can be set to zero for zero input. Then a one-point calibration defines the calibration curve that plots output versus input (next slide).
- If the linearity is unknown,
  - a two-point calibration should be performed and these two points plus the zero point plotted to ensure linearity (next slide).
- If the resulting curve is nonlinear,
  - many points should be measured and plotted to obtain the calibration curve.
- If the output cannot be set to zero for zero input,
  - measurements should be performed at zero and full scale for linear instruments and at more points for nonlinear instruments.
- Calibration curves should be obtained at several expected temperatures to determine temperature drift of the zero point and the gain.

Calibration…

- (a) The one-point calibration may miss nonlinearity.
- (b) The two-point calibration may also miss nonlinearity.



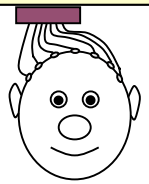
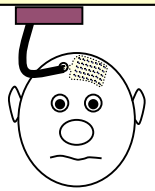
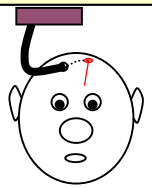
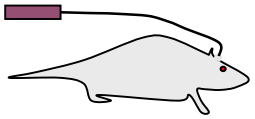
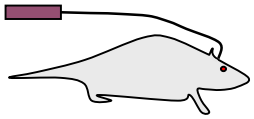
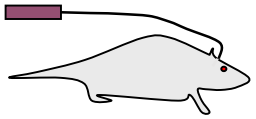
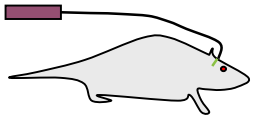
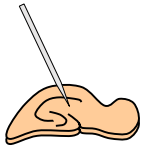
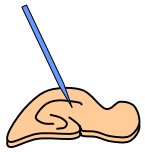
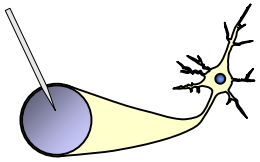
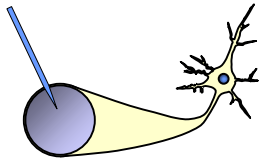
(a)



(b)

Electrodes

Introduction: types of neural microsystems applications

	External electrodes	Subdural electrodes	Micro-electrodes	Microsensors
Human level				–
Animal level				
Tissue slice level	–	–		
Cellular level	–	–		

In vivo applications

In vitro applications

What are biopotentials

Many types of cells in the body have the ability to undergo a transient electrical depolarization and repolarization.

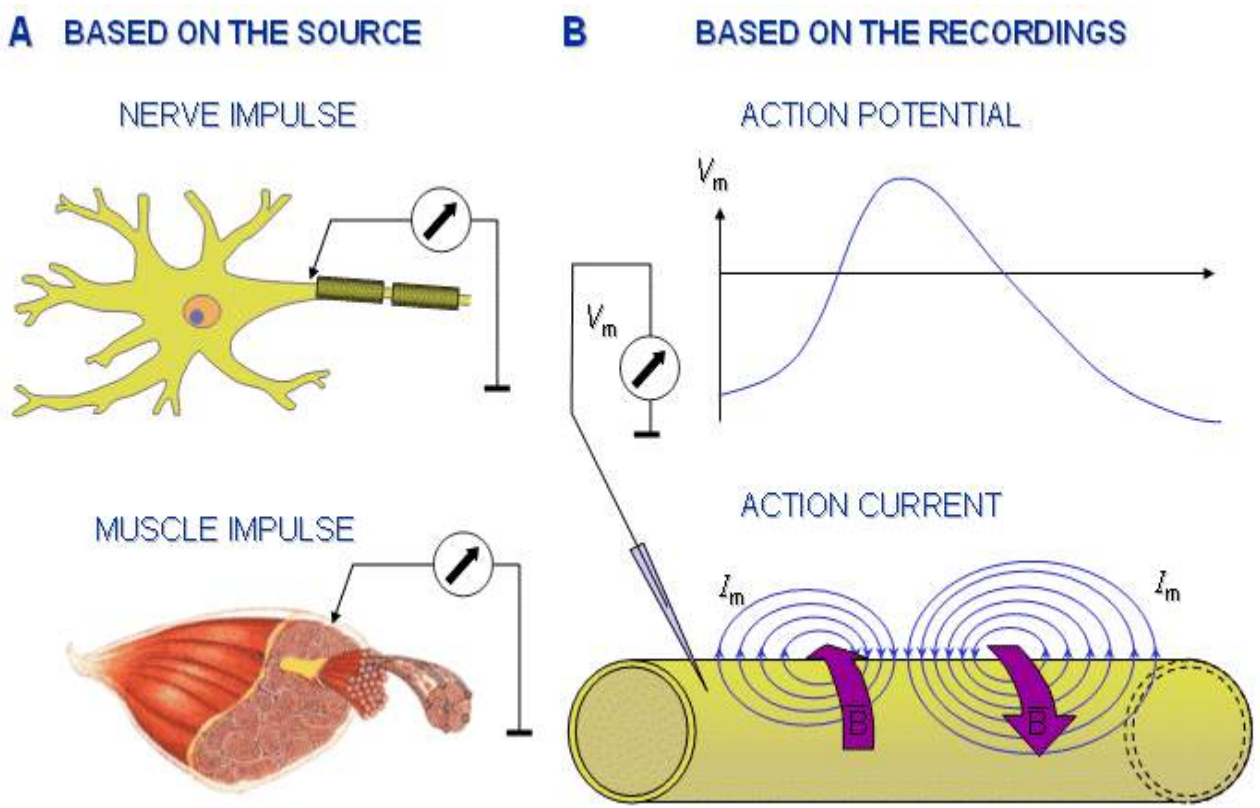
These are either triggered by external depolarization (in the heart) or by intracellular, spontaneous mechanisms.

Cells that exhibit the ability to generate electrical signals are called electrogenic cells.

The most prominent electrogenic cells include brain cells or neurons and heart cells or cardiomyocytes. (e.g. cardiac pacemaker cells), muscular cells.

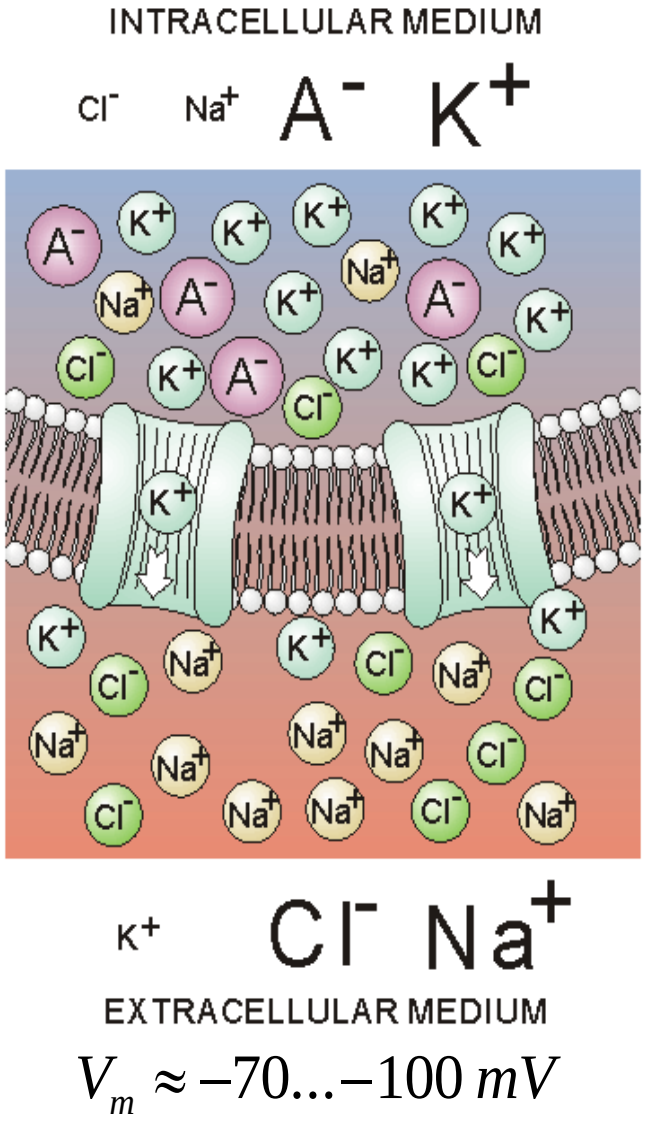
What are biopotentials

- Biopotential: An electric potential that is measured between points in living cells, tissues, and organisms, and which accompanies all biochemical processes.
- Also describes the transfer of information between and within cells



Mechanism behind biopotentials

- Action potentials are generated by special types of voltage-gated ion channels
- Concentration of potassium (K+) ions is 50-100 times higher inside as compared to outside
- Sodium ion (Na+) concentration is 10 times higher outside the membrane than inside
- In resting state the member is permeable only for potassium ions



$$V_m \approx -70 \ldots -100\ mV$$

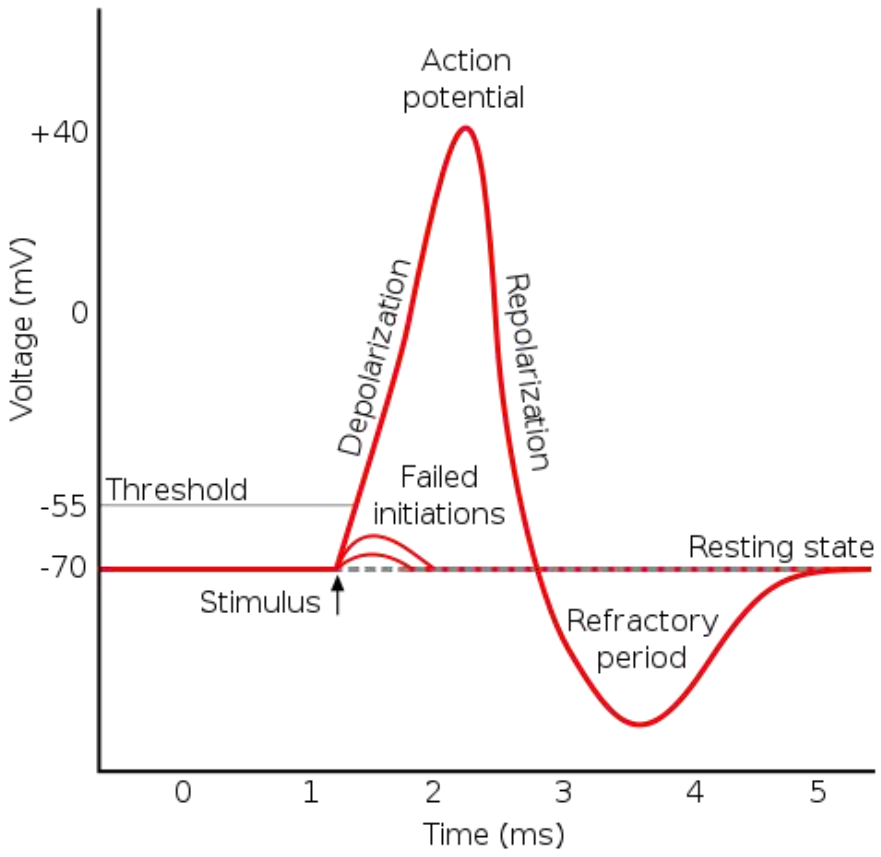
Ion Concentration

For frog skeletal muscle, typical values for the intracellular and extracellular concentrations of the major ion species (in millimoles per liter) are as follows.

Species	Intracellular	Extracellular
Na^+	12	145
K^+	155	4
Cl^-	4	120

Action Potential

- **Sodium ion** channels open, allowing the entry of sodium ions into the cell. This is followed by the opening of potassium ion channels that permit the exit of potassium ions from the cell.
- The inward flow of sodium ions increases the concentration of positively charged cations in the cell and causes depolarization, where the potential of the cell is higher than the cell's resting potential.
- The sodium channels close at the peak of the action potential, while potassium continues to leave the cell. The efflux of potassium ions decreases the membrane potential or hyperpolarizes the cell. For small voltage increases from rest, the potassium current exceeds the sodium current and the voltage returns to its normal resting value, typically −70 mV



Membrane states

Three states of cell membrane

- polarized: the cell membrane is at a steady resting potential
- depolarized: when the magnitude of membrane potential decreases (from negative/rest value)
- hyperpolarization: increase in magnitude of membrane potential

Action potential: brief transient disturbance of membrane potential

- change in membrane potential due to a stimulus adequate to bring about depolarization sufficient to exceed its threshold potential and thereby elicit an all-or-none action potential.
- change in potential from resting level requires a certain amount (of potential) for a fixed duration of time, for example: a nerve fiber, $\Delta v \approx 120$ mV and the duration is ≈1 ms. Further increases in intensity or duration of stimulus beyond that required for exceeding the threshold level produce only the same result

Return to resting state

- repolarization: return to membrane equilibrium after action potential

Ion Concentration

Maintaining steady state ionic imbalance

- requires continuous transport of ions against electrochemical gradients

Active transport mechanism located in the membrane

- the sodium–potassium pump actively transports Na+ out of cell and K+ into cell in the ratio 3Na+: 2K+
- As a result there is net outward current that tends to increase the negativity of the intracellular potential
- energy for the pump is provided by a common source of cellular energy, adenosine triphosphate (ATP) produced by mitochondria in the cell

Factors influencing the flow of ions across the membrane

- diffusion gradients
- inwardly directed electric field
- membrane structure (availability of pores)
- active transport of ions against an established electrochemical gradient

Mechanism behind biopotentials

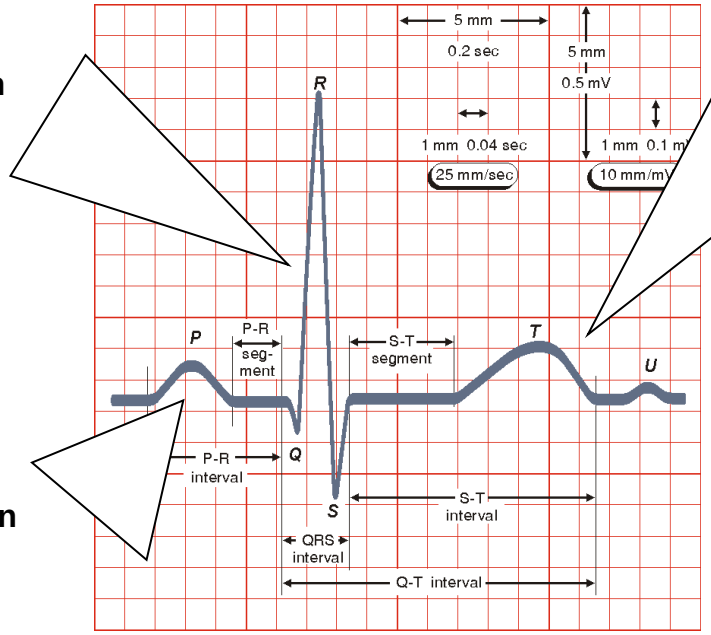
- When membrane stimulation exceeds a threshold level of about 20 mV, so called action potential occurs:
  - Sodium and potassium ionic permeabilities of the membrane change
  - Sodium ion permeability increases very rapidly at first, allowing sodium ions to flow from outside to inside, making the inside more positive
  - The more slowly increasing potassium ion permeability allows potassium ions to flow from inside to outside, thus returning membrane potential to its resting value
  - While at rest, the Na-K pump restores the ion concentrations to their original values

Electrocardiography (ECG)

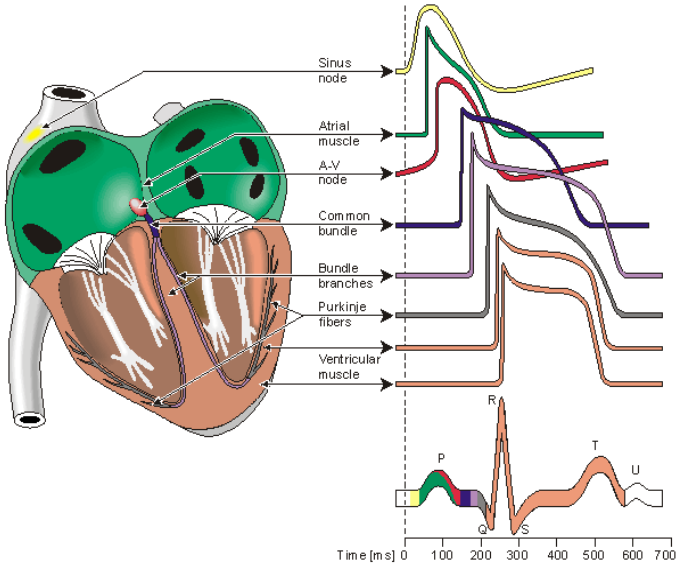
- Measures the electric activity of the heart
- Very widely used method in clinical environment
- Very high diagnostic value

2. Ventricular depolarization

1. Atrial depolarization



Ventricular repolarization

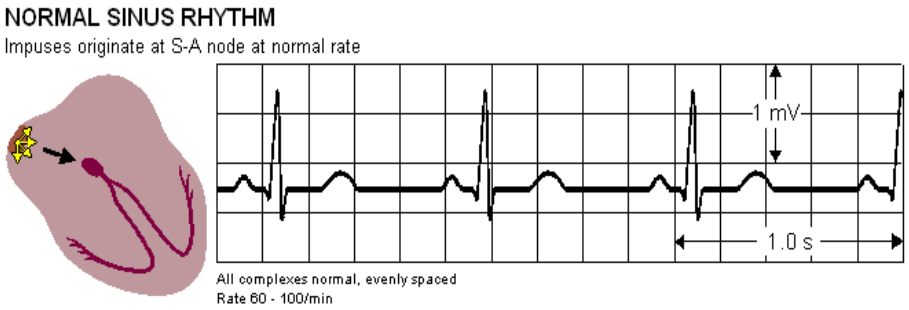


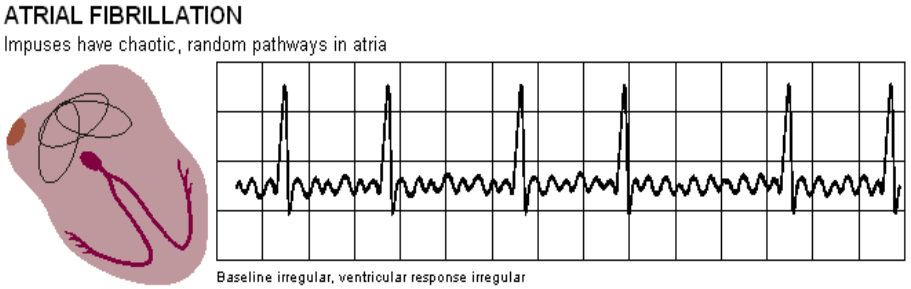
ECG basics

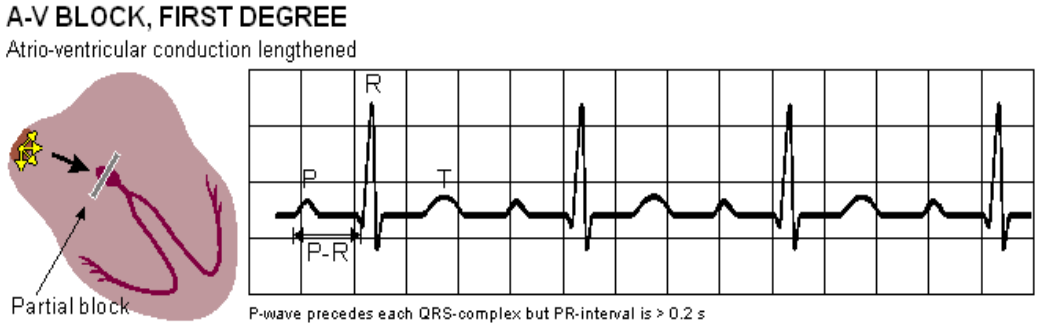
- Amplitude: 1-5 mV
- Bandwidth: 0.05-100 Hz

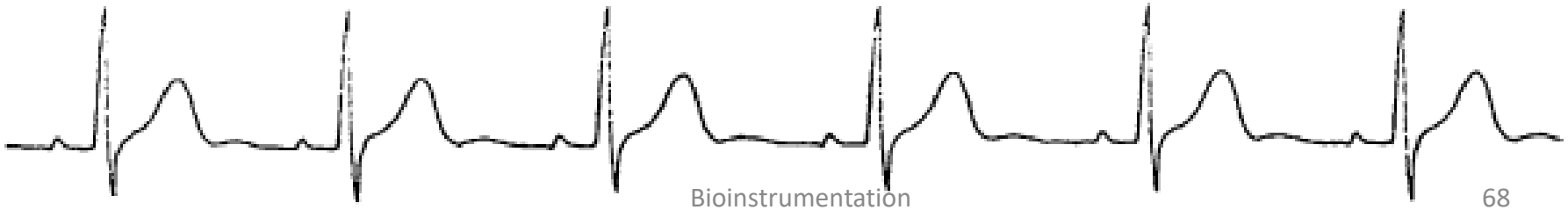
- Largest measurement error sources:
  - Motion artifacts
  - 50/60 Hz powerline interference

- Typical applications:
  - Diagnosis of ischemia
  - Arrhythmia
  - Conduction defects



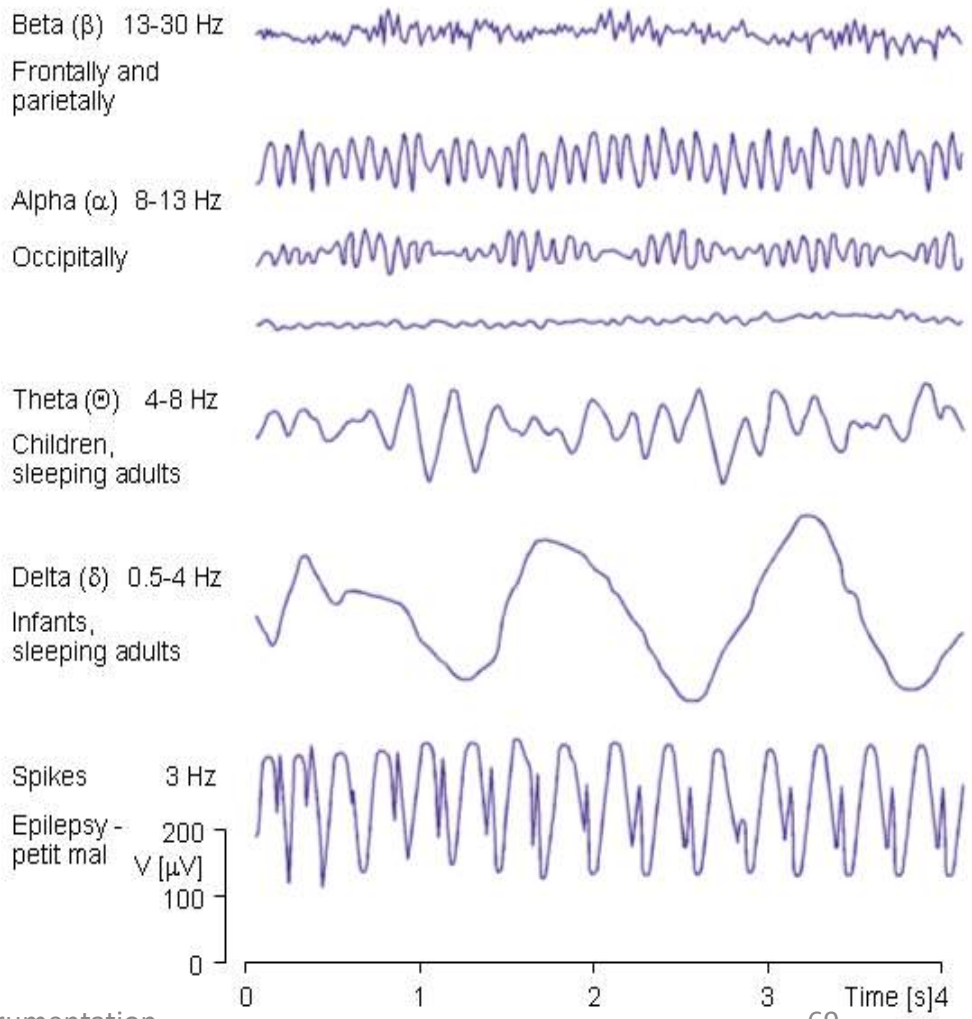






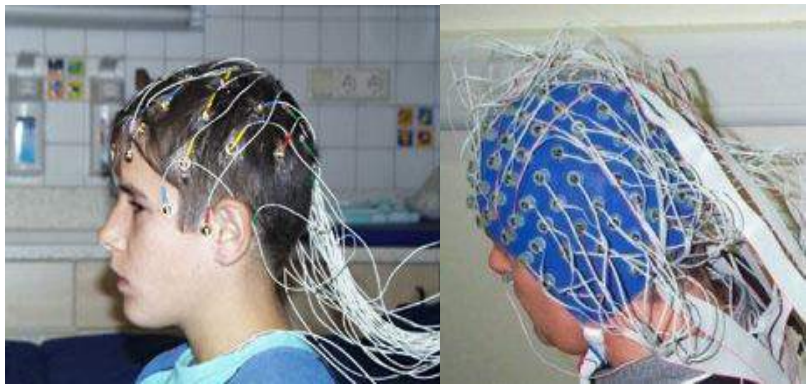
Electroencephalography (EEG)

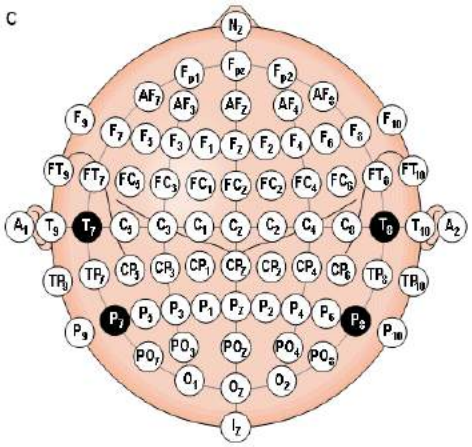
- Measures the brain's electric activity from the scalp
- Measured signal results from the activity of billions of neurons
- Amplitude: 0.001-0.01 mV
- Common Bandwidth: 0.5-40 Hz
- Errors:
  - Thermal RF noise
  - 50/60 Hz power lines
  - Blink artifacts and similar
- Typical applications:
  - Sleep studies
  - Seizure detection
  - Cortical mapping

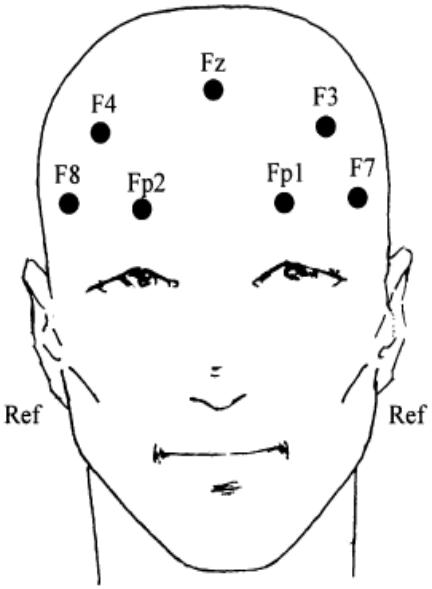


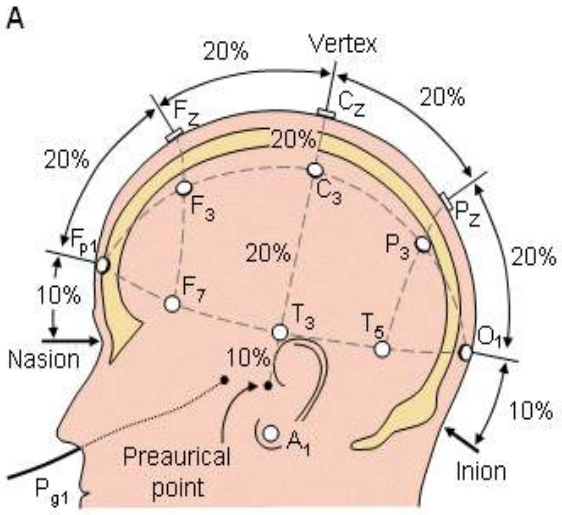
EEG measurement setup

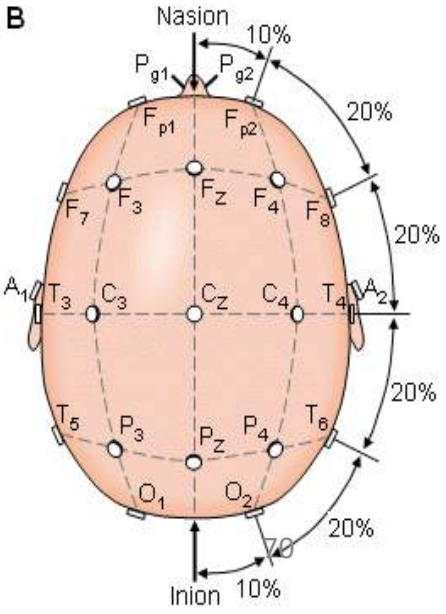
- 10-20 Lead system is most widely clinically accepted
- Certain physiological features are used as reference points
- Allow localization of diagnostic features in the vicinity of the electrode
- Often a readily available wire or rubber mesh is used
- Brain research utilizes even 256 or 512 channel EEG hats



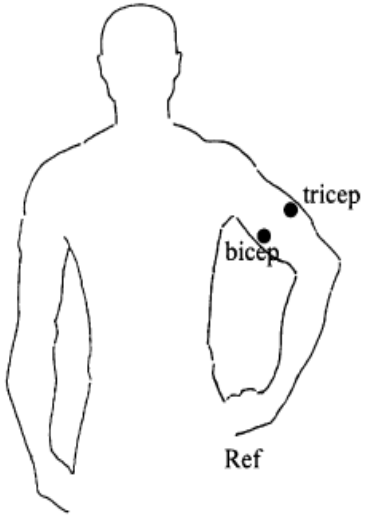








Electromyography (EMG)



- Measures the electric activity of active muscle fibers
- Electrodes are always connected very close to the muscle group being measured
- Rectified and integrated EMG signal gives rough indication of the muscle activity
- Needle electrodes can be used to measure individual muscle fibers

- Amplitude: 1-10 mV
-

-

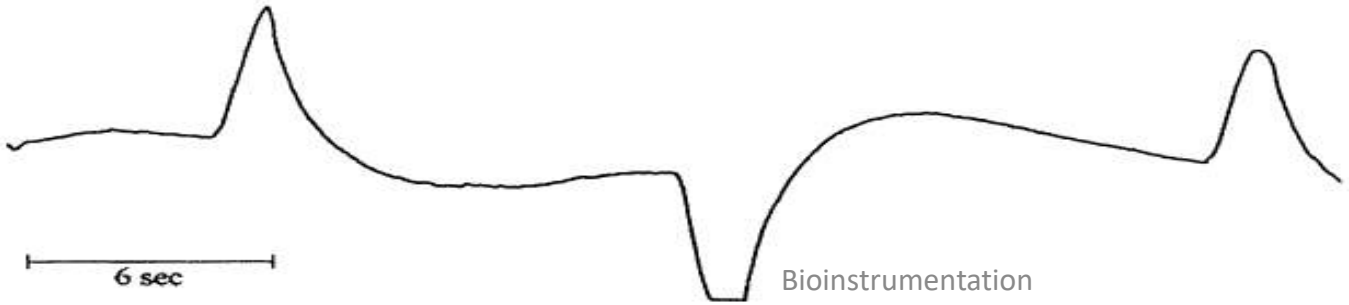
- Applications: muscle function, neuromuscular disease, prosthesis

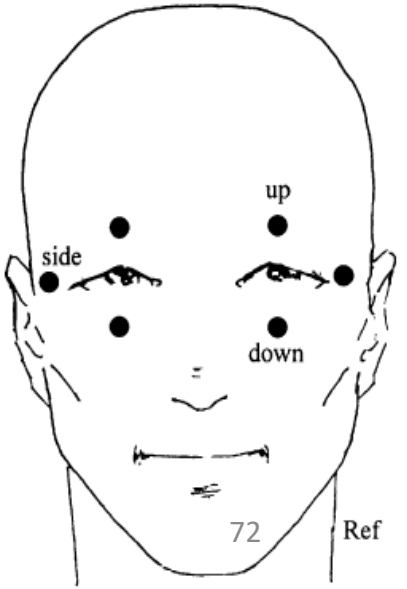
Electrooculography (EOG)

- Electric potentials are created as a result of the movement of the eyeballs
- Potential varies in proportion to the amplitude of the movement
- In many ways a challenging measurement with some clinical value

- Amplitude: 0.01-0.1 mV
- Bandwidth: DC-10 Hz

- Primary sources of error include skin potential and motion
- Applications: eye position, sleep state etc.





Biopotential Electrodes – The Basics

- The interface between the body and electronic measuring devices
- Conduct current across the interface
- Current is carried in the body by ions
- Current is carried in electronics by electrons
- Electrodes must change ionic current into electronic current
- This is all mediated at what is called the Electrode-Electrolyte Interface or the Electrode-Tissue Interface

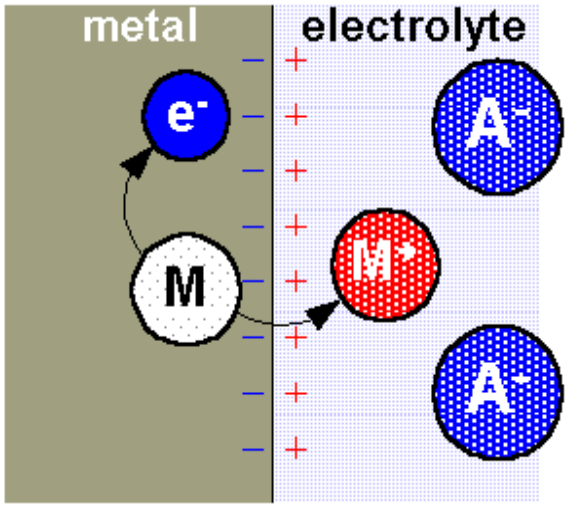
WHAT ARE ELECTRODES?

Electrodes are the means by which liquids and living organisms are included in electrical circuits.

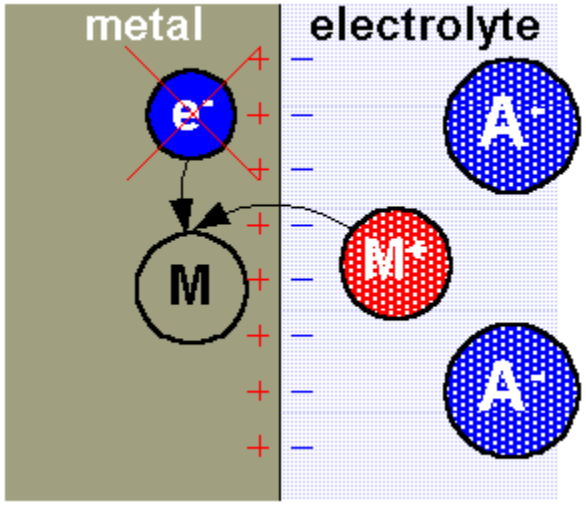
To understand how this works lets focus on half cell potential.

Electrode-electrolyte interface

- Current flow from electrode to electrolyte : Oxidation (Loss of e^-)
- Current flow from electrolyte to electrode : Reduction (Gain of e^-)



electrode to electrolyte



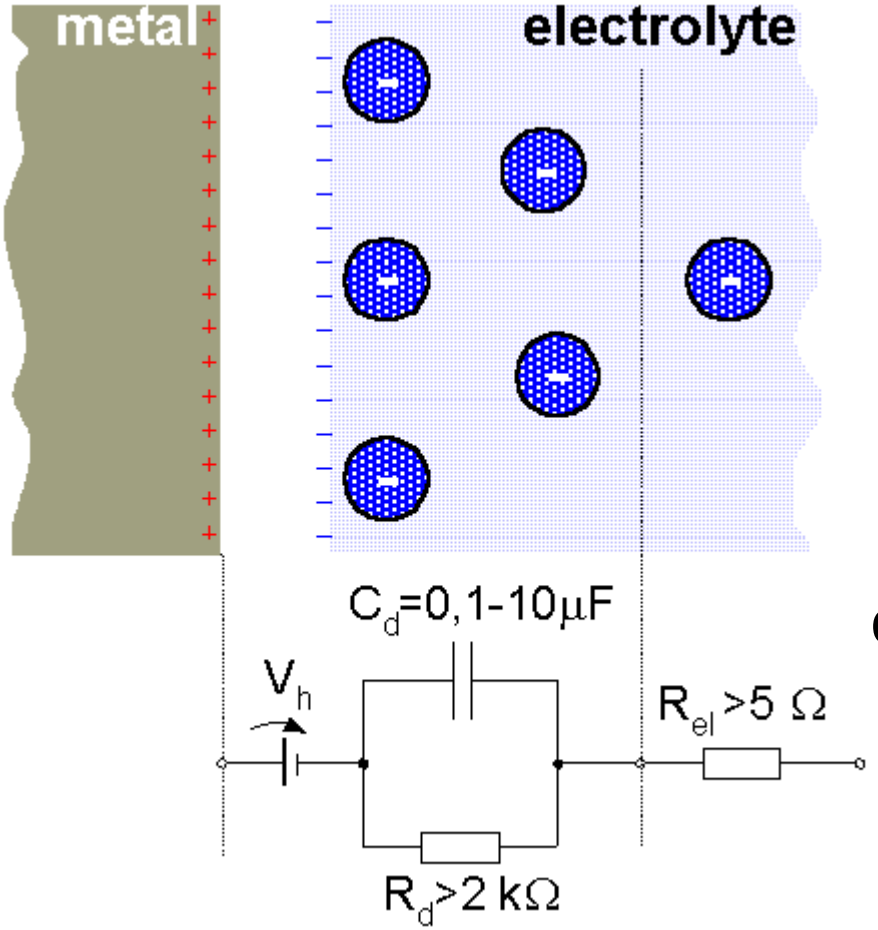
electrolyte to electrode

Electrode-electrolyte interface

A characteristic potential difference 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) .

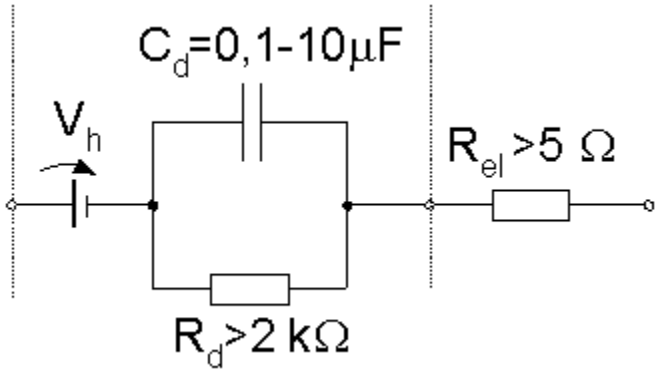
Reason for Half Cell Potential : Charge Separation at Interface
Oxidation or reduction reactions at the electrode-electrolyte interface lead to a double-charge layer, similar to that which exists along electrically active biological cell membranes.

Electrode-electrolyte interface

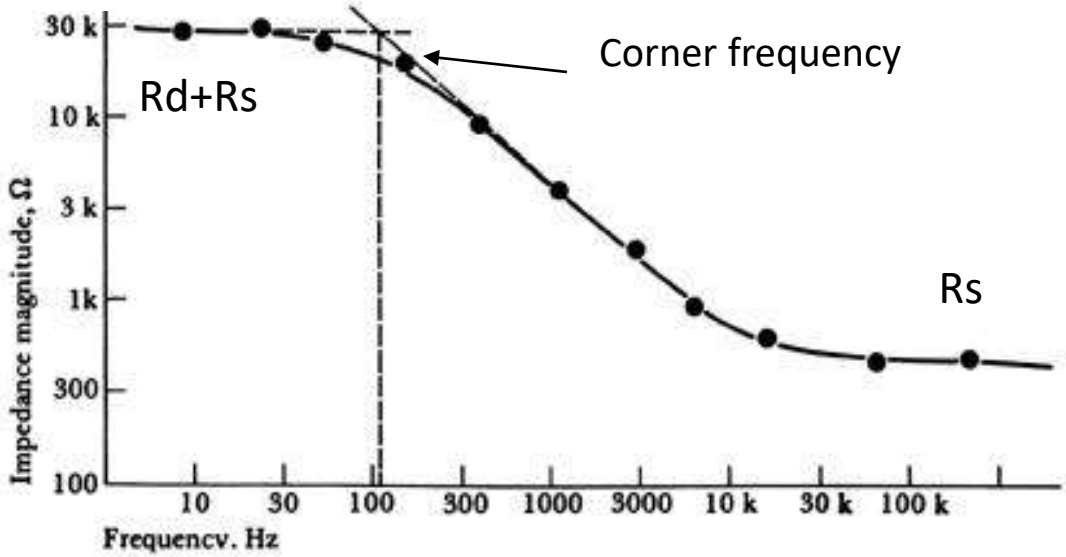


equivalent circuit

Electrode-electrolyte interface



C_d : capacitance of electrode-eletrolyte interface
R_d : resistance of electrode-eletrolyte interface
R_{el} : resistance of electrolyte
V_h : cell potential for electrode
R_s : resistance of electrode lead wire



Frequency Response

Problem with the electrodes: **polarization**

Polarization – arises in case when current flows between the electrode and the solution.

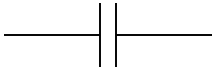
Perfectly polarizable electrodes – no actual current crosses the electrode-electrolyte interface

Nonpolarized electrodes – allow the current to pass freely in electrode-electrolyte interface.

Polarizable and Non-Polarizable Electrodes

Use for recording

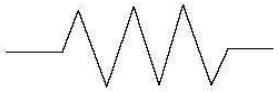
Perfectly Polarizable Electrodes



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

Perfectly Non-Polarizable Electrode

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



Use for stimulation

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

The Skin

Structure of the Skin.

The skin is a multi layered organ.

It is made up of three principal layers—

- the epidermis (outer layer, 100 micro m thick),
- the dermis (middle layer, 2 mm thick,),
- and the subcutaneous layer (connecting tissue).

Skin Impedance

The epidermis is mainly non-conducting so offers high impedance.

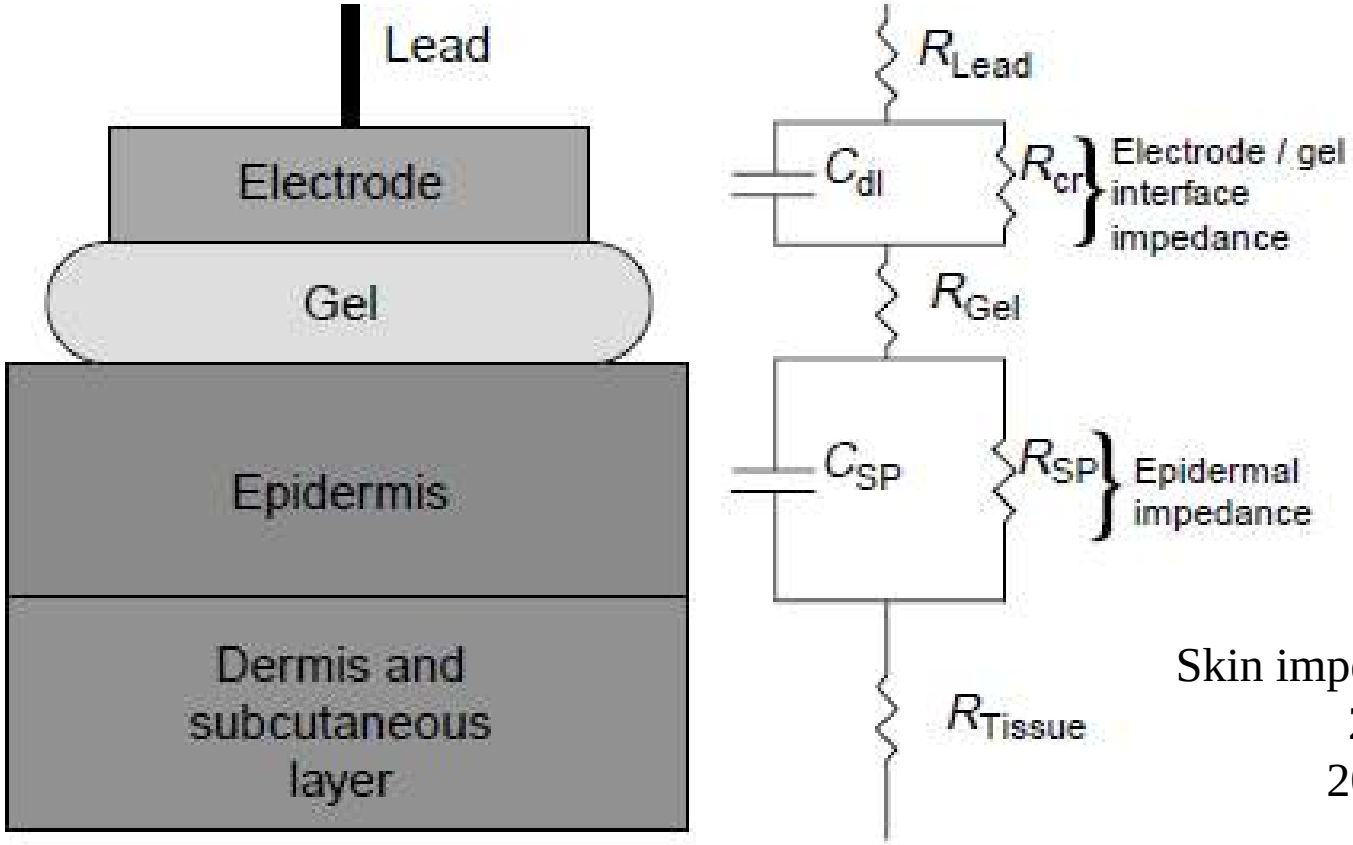
It behaves like a capacitive couple between electrode and dermis/subcutaneous layer

One can imagine the relatively nonconductive epidermis sandwiched between the conductive electrode and the conductive tissues forming a parallel plate capacitor.

Skin Impedance

In reality Skin behaves like a leaky capacitor In which some ions may pass from epidermis. The flow of ionic current can be represented electrically by a large resistance, R_{SP}, in parallel with C_{SP} (see following slide).

Skin Impedance



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

Skin Impedance

Inner layers (dermis and subcutaneous) are many composed of wet elements (glands, tissues, other body fluids). So it can be modeled by simple Resistance of the tissue R_{tissue} (previous slide)

Skin Impedance

The complete skin impedance model includes the electrode lead resistance, R_{Lead}; the electrode–gel interface impedance (the double-layer capacitance, C_{dl}, in parallel with the charge transfer resistance, R_{CT}); the gel resistance, R_{Gel}; the skin impedance (the parallel combination of a capacitance, C_{SP} and a resistance, R_{SP}), and the underlying tissue resistance, R_{Tissue}.

Skin Impedance (Home Work)

Does fair colored skin and dark colored skin have same impedance?

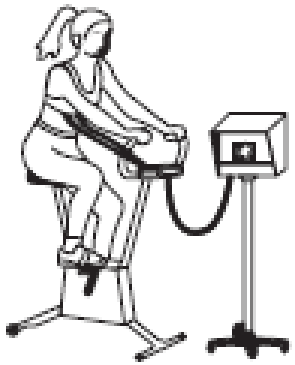
You have designed a new electrode system or associated device and want to test on a range of subjects. Is it possible that what may work well on a fair skin subject in a warm and humid environment may not work on a dark skin subject in a cold or dry environment?

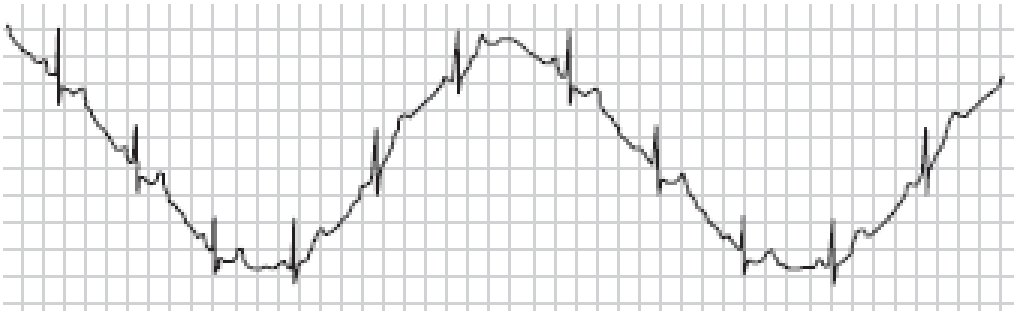
Motion Artifact

Why

Thickness of epidermal layer is very important recordings. If the thickness of the layer is changed by stretching or pressing down on the skin, the skin potential can vary by 5–10mVcompared with, for example, the 1 or 2 mVECG signal.

As these fluctuations generally result from patient movement, they are termed motion artifact.





Motion Artifact

Solutions:

- Use high concentrated gels, high concentrate gels increase the skin potential and hence signals can easily measured.
- Avoid hydro-gels, hydrogels try to dehydrate the skin, thus increase the skin impedance.
- Foam based electrodes tends to absorb any pull on the electrode to avoid artifacts.
- Motion artifact is minimal for non-polarizable electrodes

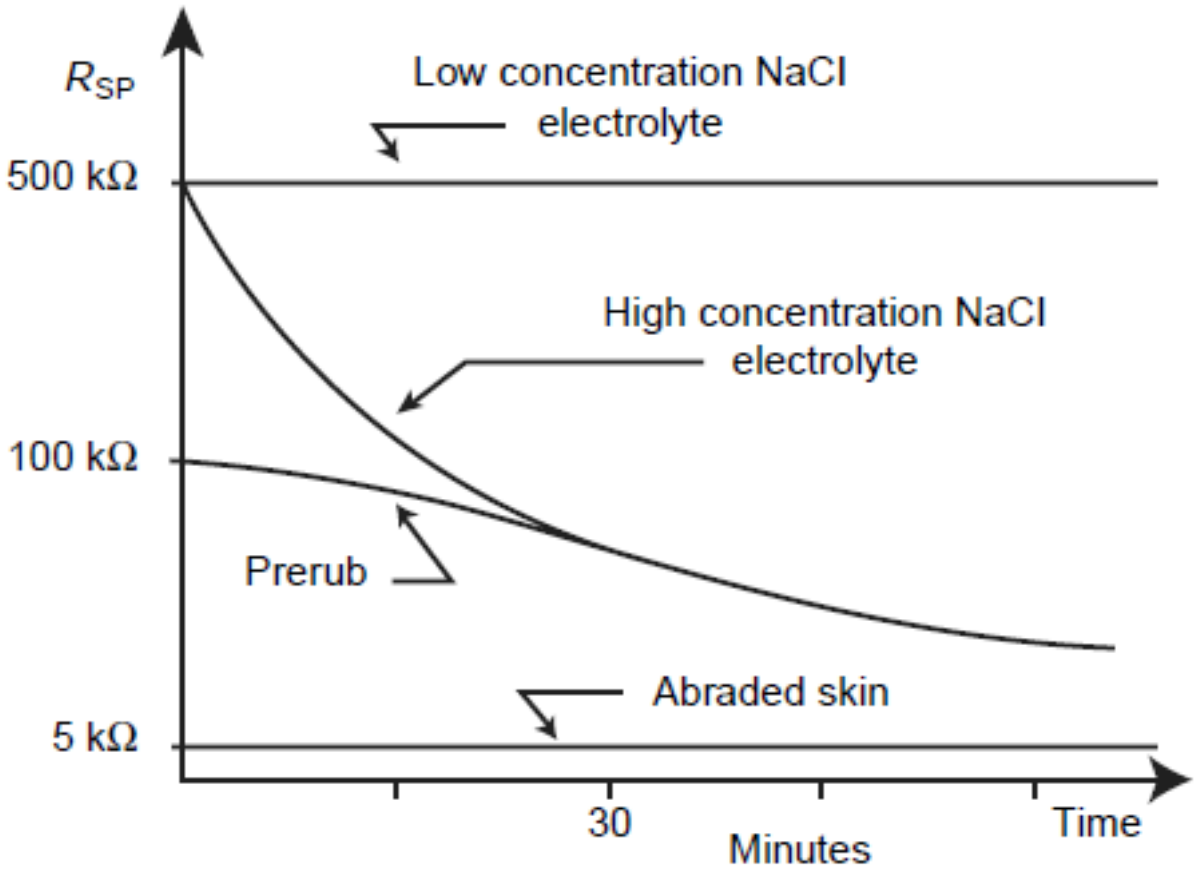
Electrode Gels:

- ensure a good electrical contact between the electrode and the patient's skin.
- facilitate the transfer of charge at the electrode-electrolyte interface between the two kinds of charge carrier (electrons in the electrode and ions in the gel),
- decrease the large impedance of the stratum corneum (epidermis)

Main types of Electrode Gels:

1. **Wet gels** (often described as pastes, creams, or jellies)

Wet gels are generally composed of water, a thickening agent, a bactericide/fungicide, ***ionic salts***, and a surfactant



Variation of skin resistance with time for a range of Wet gel concentrations and skin preparation techniques

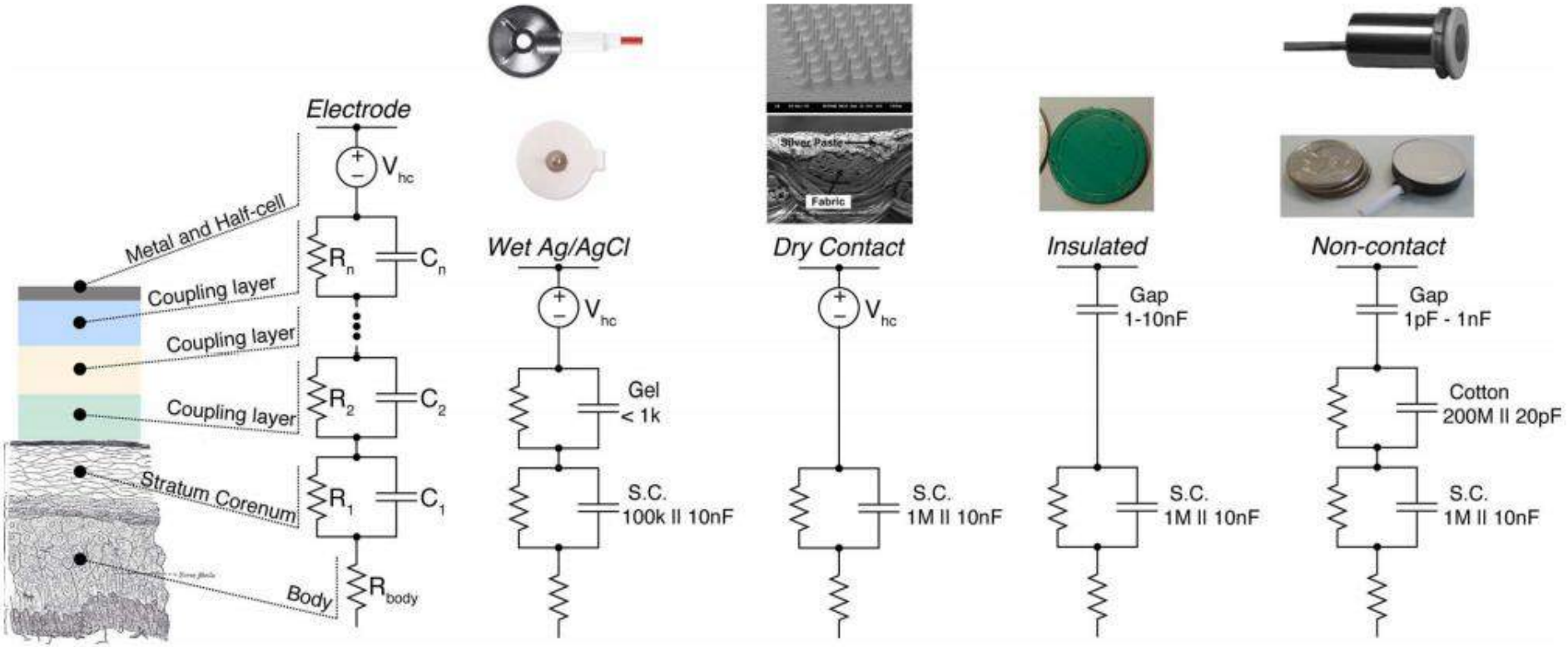
In summary, For electrode gels (electrolytes), the higher the chloride salt content, the more conductive the electrode. Higher salt content, pre-gelled, surface electrodes are useful for making fast, high quality measurements of biopotentials, once the electrodes are applied to the skin surface. In addition, wet (liquid) gels further accelerate this process because the electrolyte migrates into the skin surface layers more easily and rapidly. High conductivity electrodes generally have reduced artifact, due to the low generated impedance between electrode and skin surface.

Main types of Electrode Gels:

2. **Solid Gels (Hydrogels):** Hydrogels are solid gels, which originally incorporated natural hydrocolloids.

Solid Hydrogel serves principally to ensure a good electrical contact between the skin and the electrode and that they do not significantly affect (compared with wet gels) the properties of the stratum corneum (e,g ion concentration by salts).

Solid Hydrogels are therefore not only more resistive than wet gels, they hydrate the skin less effectively and give rise to higher skin impedances

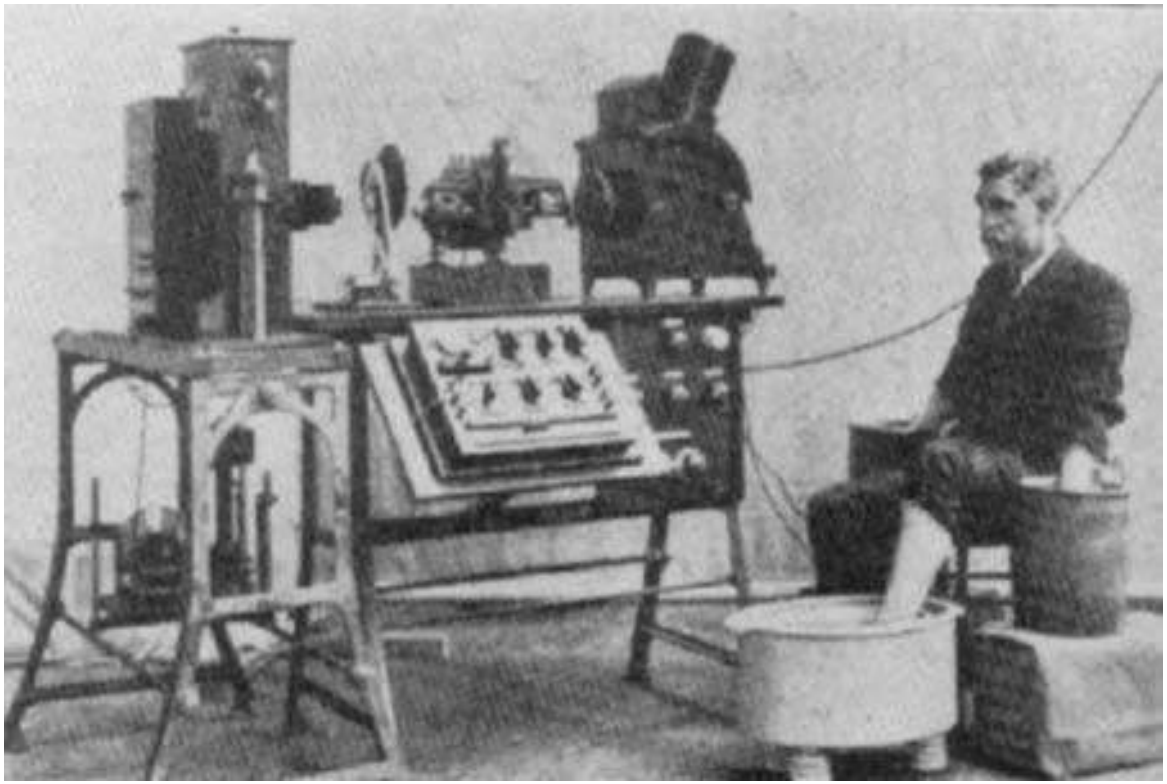


Electrical coupling of skin-electrode interface for various electrode topologies, including wet-contact gel-based Ag/AgCl, dry-contact MEMS and metal plate, thin-film insulated metal plate, and noncontact metal plate coupling through hair or clothing such as cotton

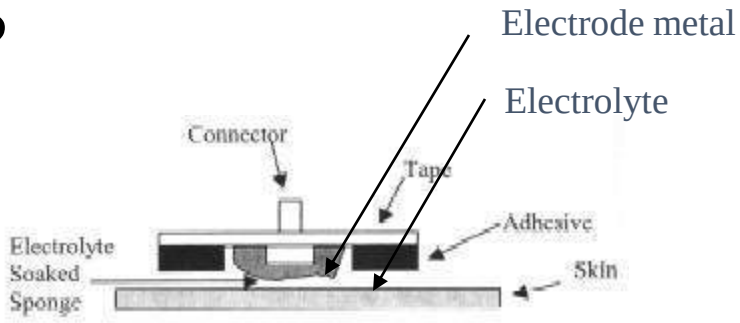
Electrode Design

External Biosignal Monitoring Electrodes

1887, Augustus Waller
Willem Einthoven



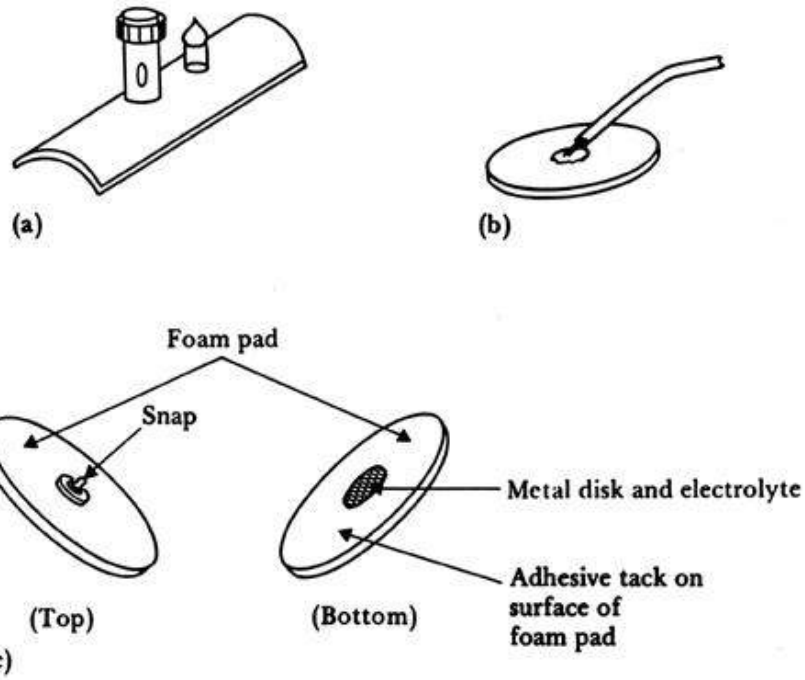
Body Surface Recording Electrodes



1. Metal Plate Electrodes (historic)
2. Suction Electrodes (historic interest)
3. Floating Electrodes
4. Flexible Electrodes

Commonly Used Biopotential Electrodes

- Metal plate electrodes
  - Large surface: Ancient, still used, ECG
  - Metal disk with stainless steel; platinum or gold coated
  - EMG, EEG
  - smaller diameters
  - motion artifacts
  - Disposable foam-pad: Cheap!

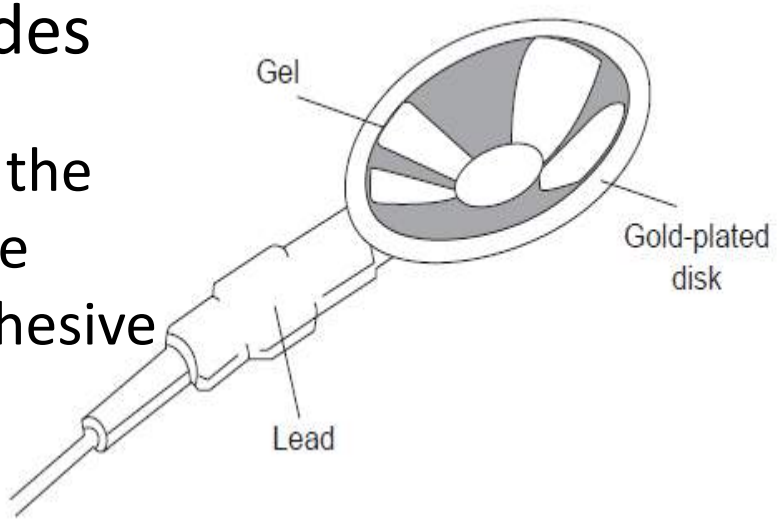


(a) Metal-plate electrode used for application to limbs.
(b) Metal-disk electrode applied with surgical tape.
(c)Disposable foam-pad electrodes, often used with ECG

Commonly Used Biopotential Electrodes

Conically formed metal disk electrodes

The base of the metal cone is attached to the patient's scalp using elastic bandages, wire mesh, or more recently, using a strong adhesive such as colloidon.

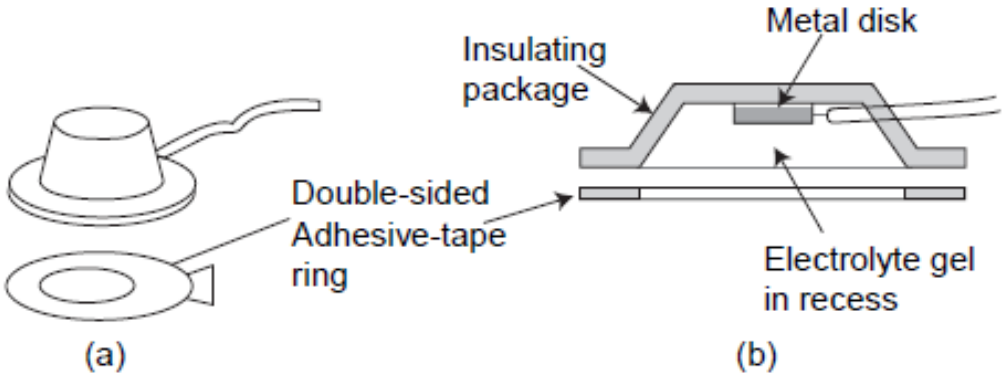


The cone electrodes are often made of gold as it has high conductivity and inertness, desirable in reusable electrodes. More recently, Ag/AgCl has been used as well.

- Skin is in direct contact with the electrode
- Considerable artifact problems due to disturbance of the double-layer region at the electrode/skin (or, more precisely, electrode/electrolyte) interface.

Commonly Used Biopotential Electrodes

Floating or recessed biosignal electrode: were introduced to address mechanical problems of disk electrodes. Now the electrode is encapsulated in a plastic housing and have no direct contact with skin.

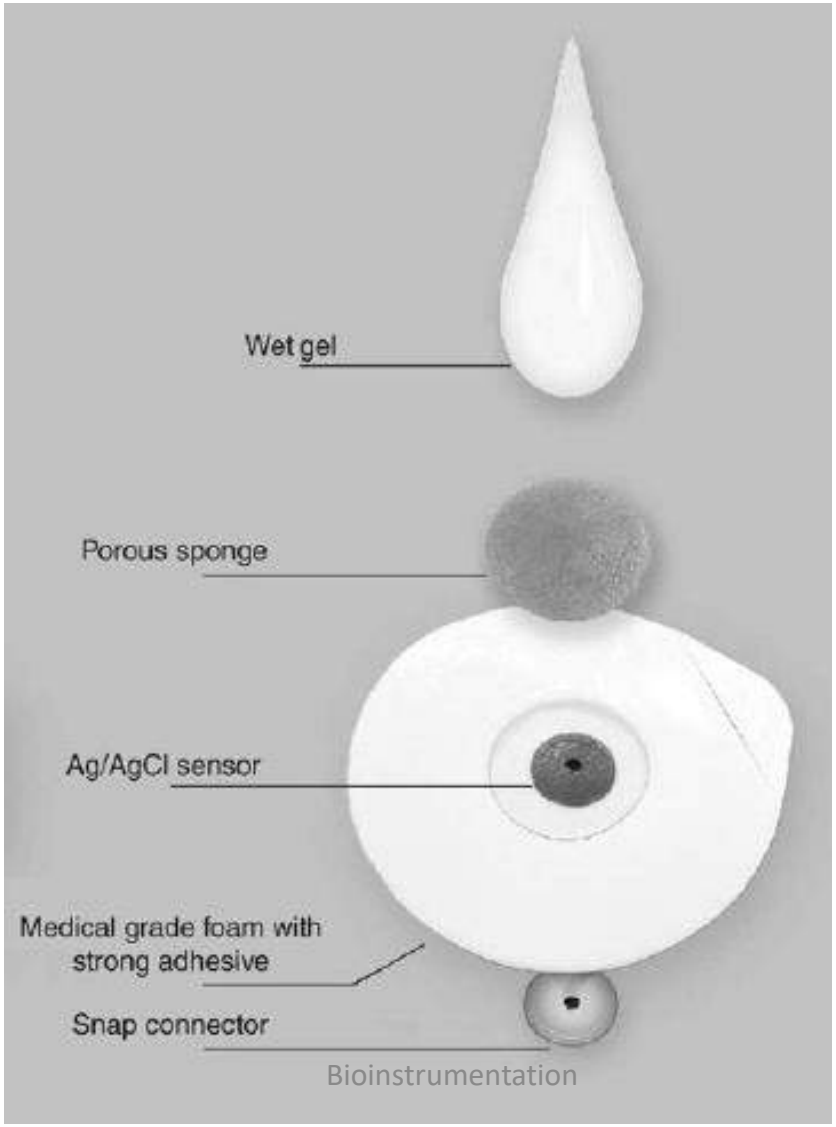


Examples of a floating or recessed biosignal electrode.

(a) Recessed electrode with top-hat structure.

(b) Cross-sectional view of the electrode in (a)

Modern Wet-gel Electrodes



Modern Wet-gel Electrodes

Offset connector electrode: A side connector is placed which is internally linked with wet gel electrode.

Modern Electrodes

Wearable electrodes
Dry electrodes

Stimulating Electrodes

Current density consideration

Stimulus electrode contact area with skin is inversely proportional to current density.

Localized Stimulation: when the target area is small
Generalized Stimulation: When the target area is larger

What are the disadvantages of stimulating larger area with one electrode?
Biopolar stimulation is often used to stimulate large muscle groups sandwiched between the (large) electrodes.

Stimulating Electrodes

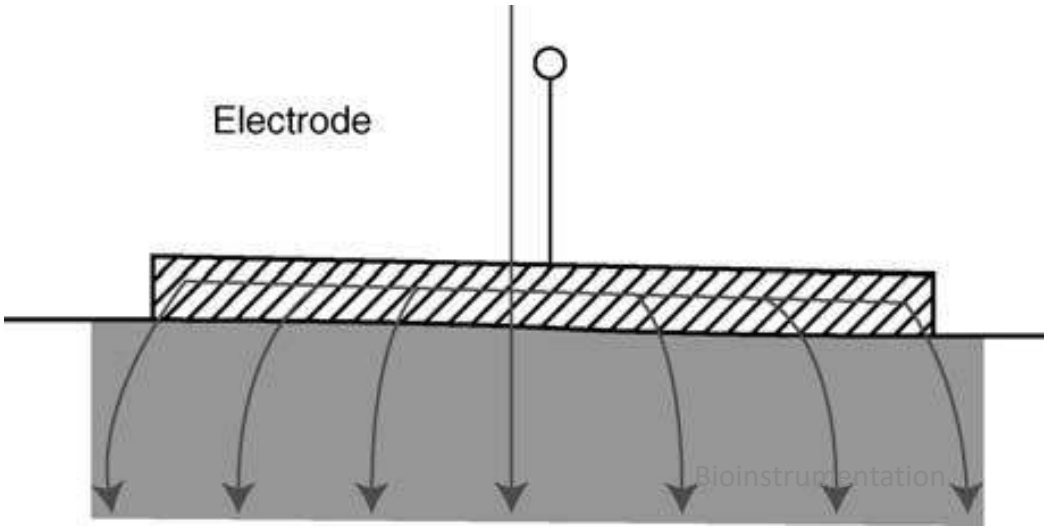
Current density consideration

High current densities can cause tissue injury due to, among other things, heating effects. The passage of electricity through any conductor will cause the dissipation of heat within that conductor. This excessive heat can produce hotspots on skin.

Types of Stimulating Electrodes

1. Conductive Electrodes

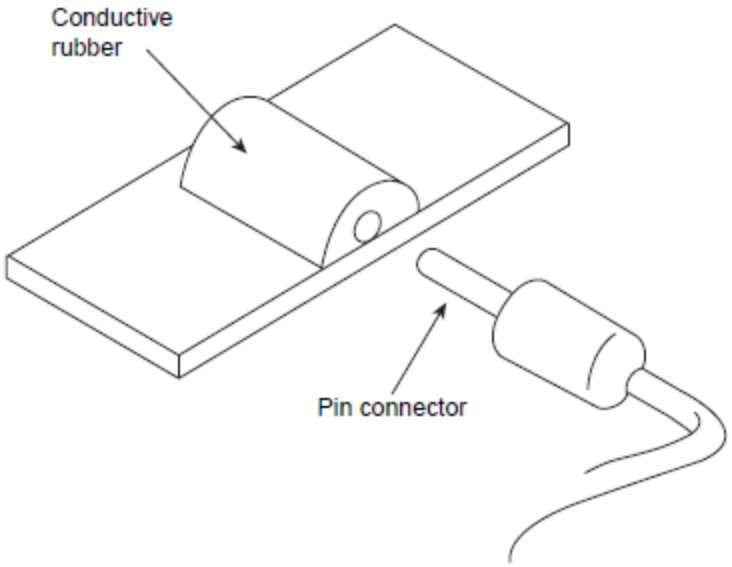
They are used to provide higher current density, With highly conductive metal electrodes, such as those used for external cardiac pacing, defibrillation, or electrosurgery.



Types of Stimulating Electrodes

2. Resistive Electrodes

They are designed to reduce the current densities under the electrodes, to reduce skin irritation problems, and to increase stimulation comfort. They are made of an elastomer (e.g., silicone rubber) or a plastic (e.g., ethylene vinyl acetate) and loaded with electrically conductive carbon black.



Implant Electrodes

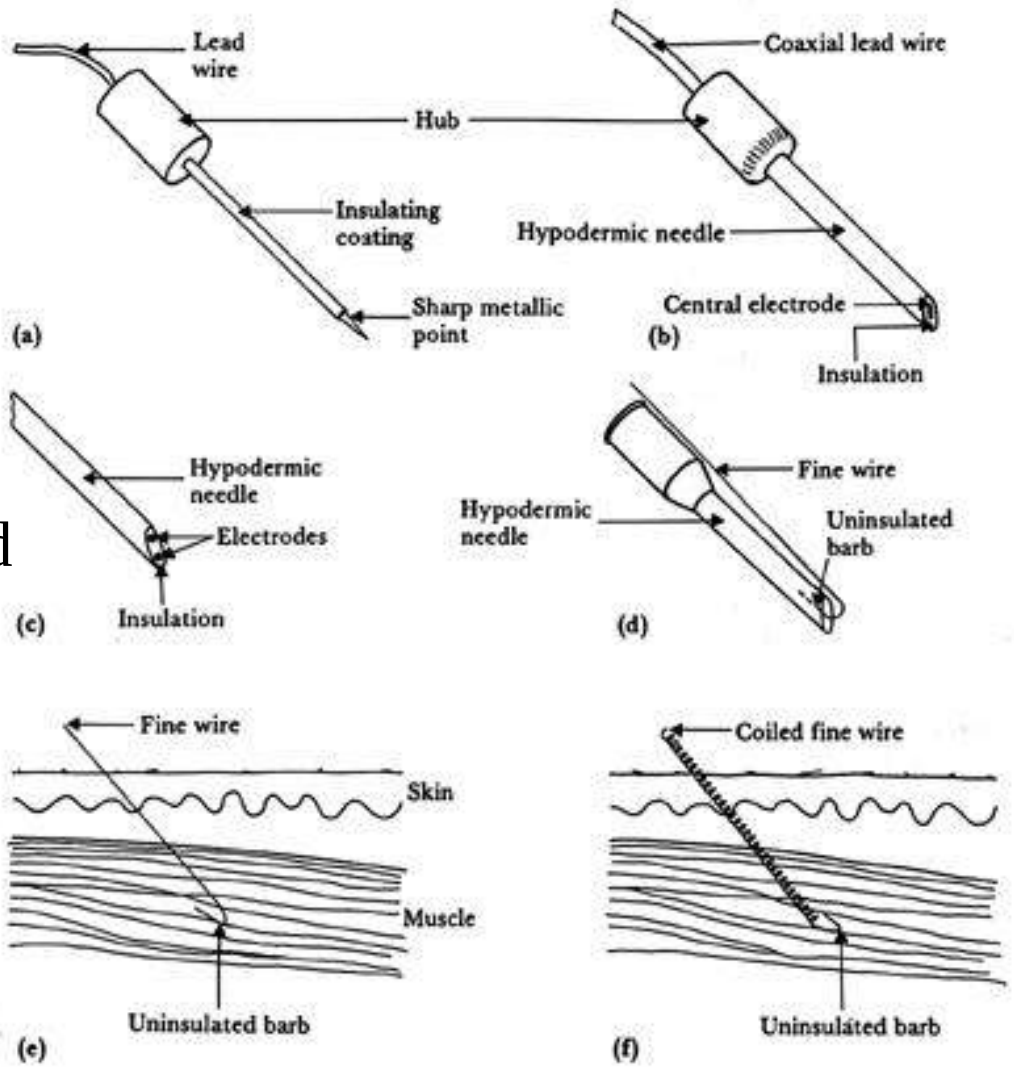
Implantable monitors/stimulators and their electrodes are used, or are being developed, for a wide range of applications, including cardiac pacing and defibrillation, cochlear implants; urinary control, phrenic nerve stimulation for respiration control; functional electrical stimulation of limbs; vagal stimulation for control of epilepsy, spinal stimulation for chronic pain relief, deep-brain stimulation for Parkinsons disease or depression, bonehealing, and several visual neuroprostheses.

Implant Electrodes

Implanted monitoring electrodes are used to more accurately pick up the desired signal while minimizing the contributions of extraneous signals. Implanted stimulation electrodes deliver the applied waveform more selectively to the targeted tissue, making the therapy more effective and, as the stimulation electrode is generally implanted away from cutaneous pain receptors and afferent nerve fibers, more comfortable for the patient.

Needle and wire electrodes for percutaneous measurement of biopotentials

(a) Insulated needle electrode.
(b) Coaxial needle electrode.
(c) Bipolar coaxial electrode.
(d) Fine-wire electrode connected to hypodermic needle, before being inserted.
(e) Cross-sectional view of skin and muscle, showing coiled fine-wire electrode in place.



The latest: BION – implanted electrode for muscle recording/stimulation
Alfred E. Mann Foundation

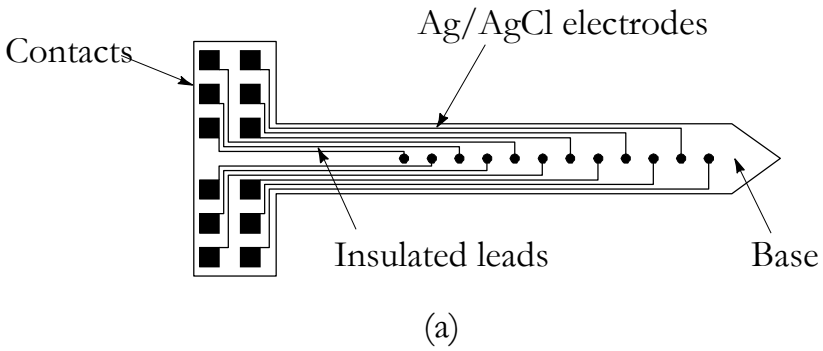
Microelectrode

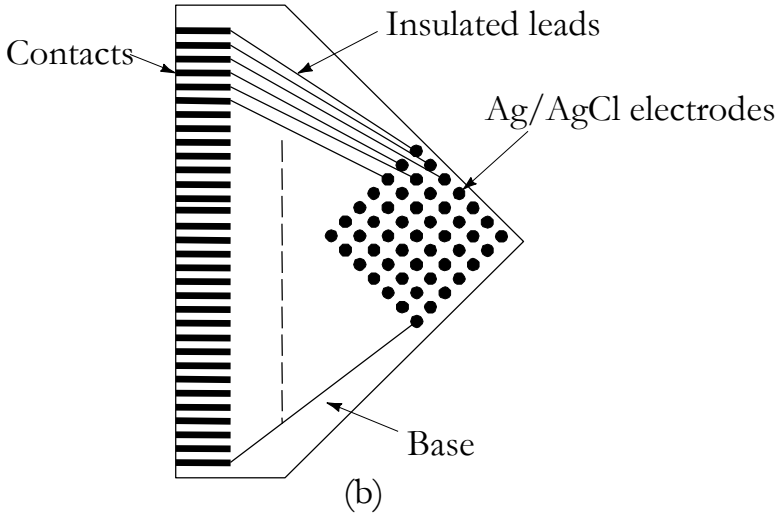
Why

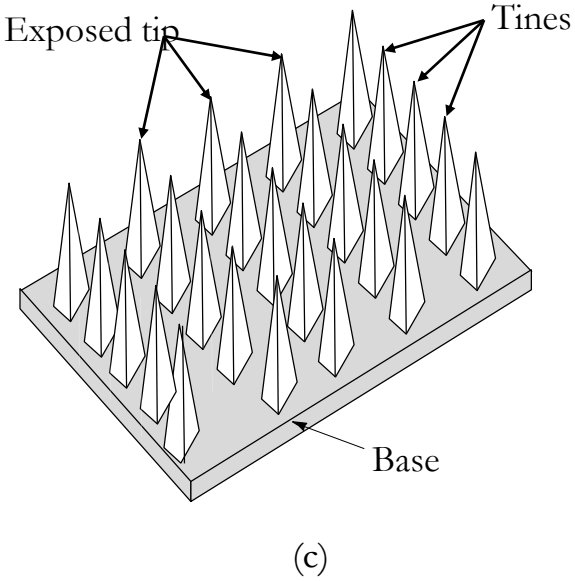
- Measure potential difference across cell membrane

- Requirements
  - Small enough to be placed into cell
  - Strong enough to penetrate cell membrane
  - Typical tip diameter: 0.05 – 10 microns
- Types
  - Solid metal -> Tungsten microelectrodes
  - Supported metal (metal contained within/outside glass needle)
  - Glass micropipette -> with Ag-AgCl electrode metal

Electrode Arrays

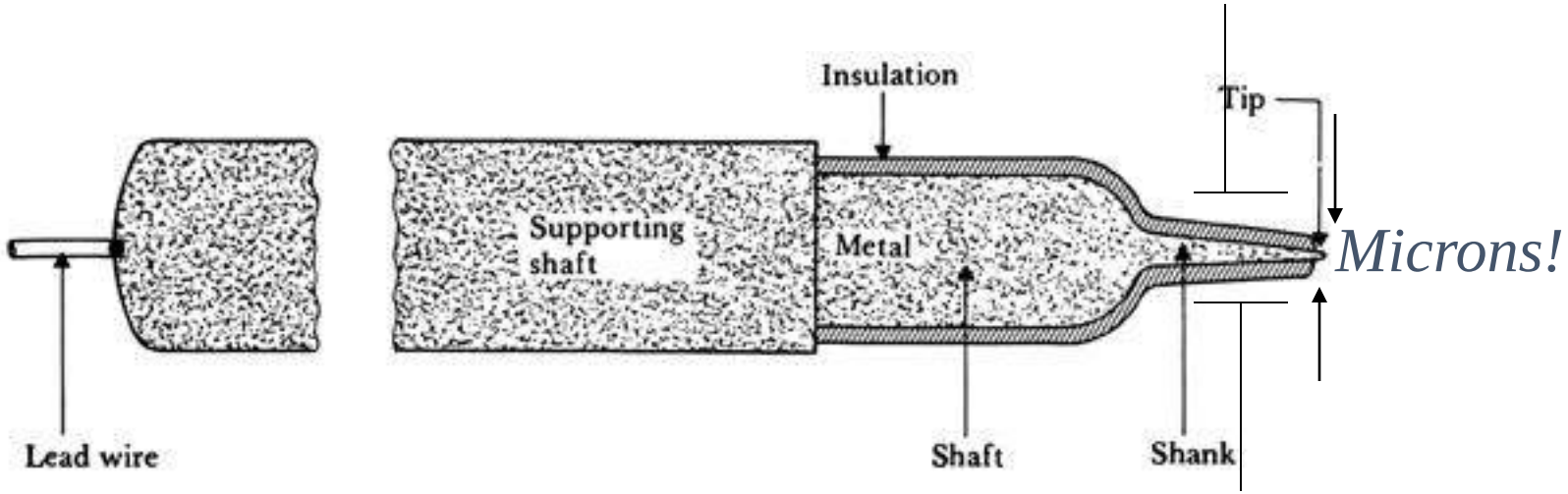






Examples of microfabricated electrode arrays.
(a) One-dimensional plunge electrode array,
(b) Two-dimensional array, and
(c) Three-dimensional array

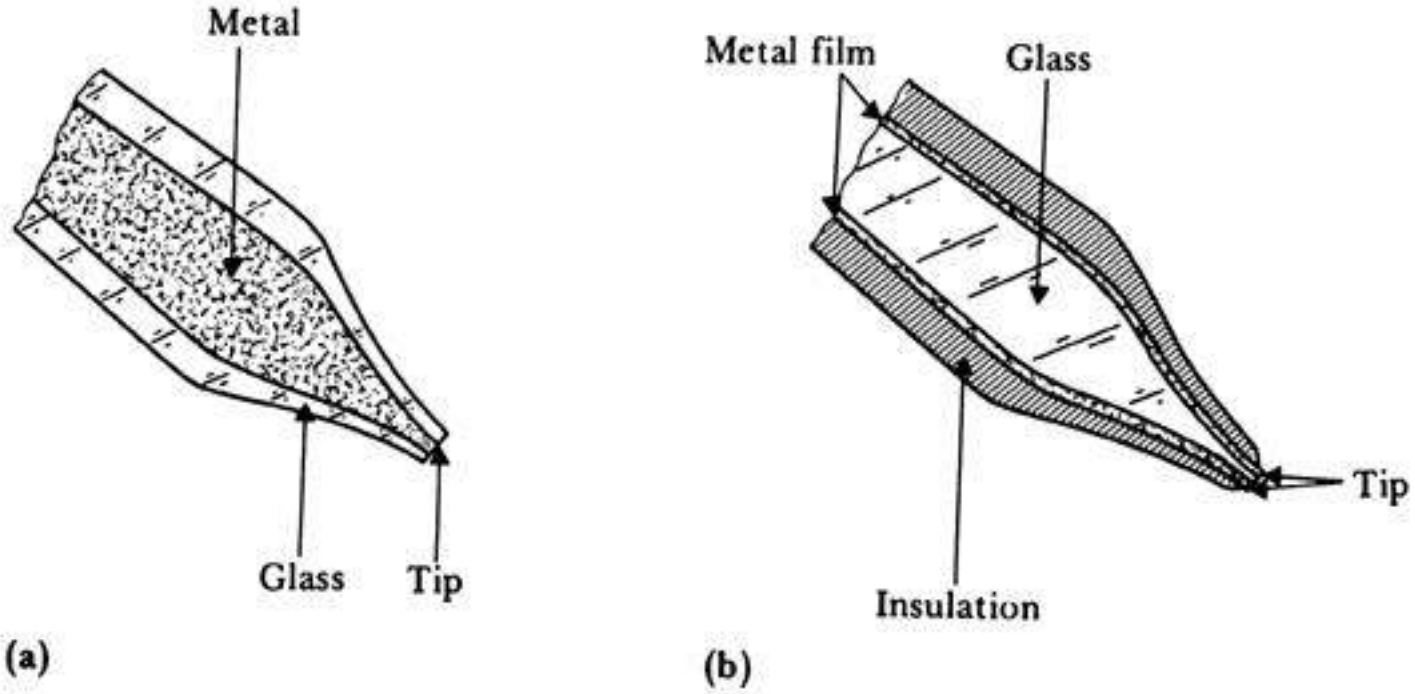
Microelectrode



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

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

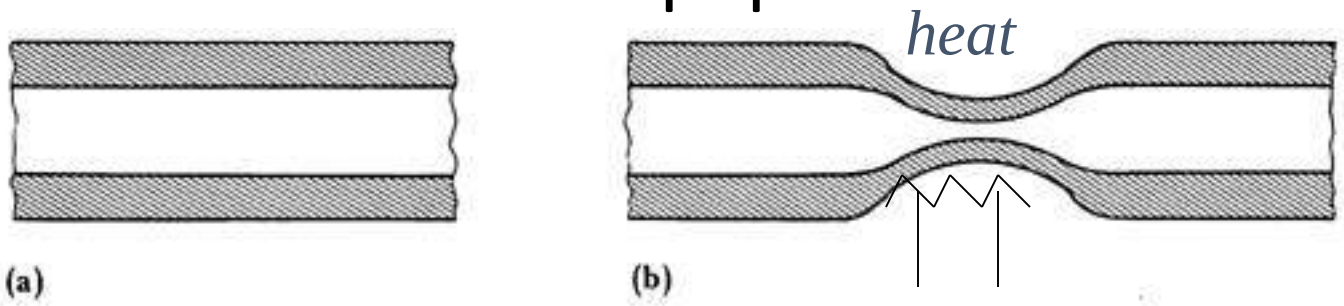
Metal supported microelectrode

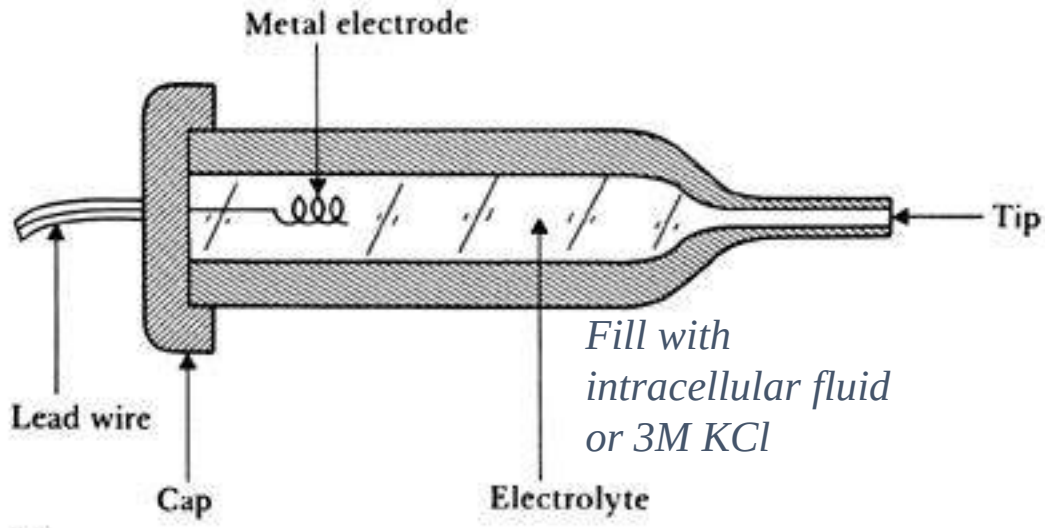


(a) Metal inside glass (b) Glass inside metal

Glass Micropipette

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



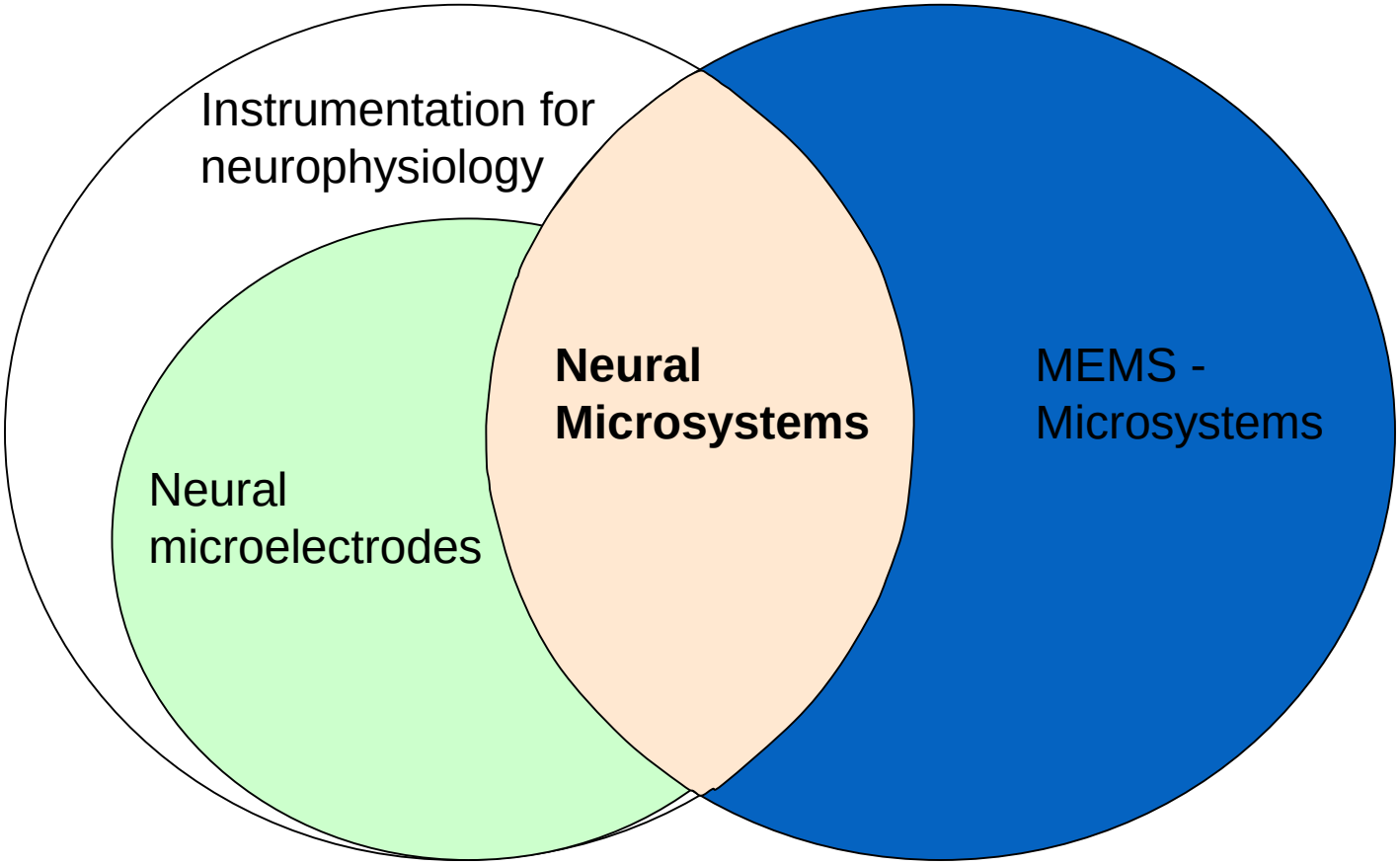


A glass micropipet electrode filled with an electrolytic solution
(a) Section of fine-bore glass capillary.
(b) Capillary narrowed through heating and stretching.
(c) Final structure of glass-pipet microelectrode.

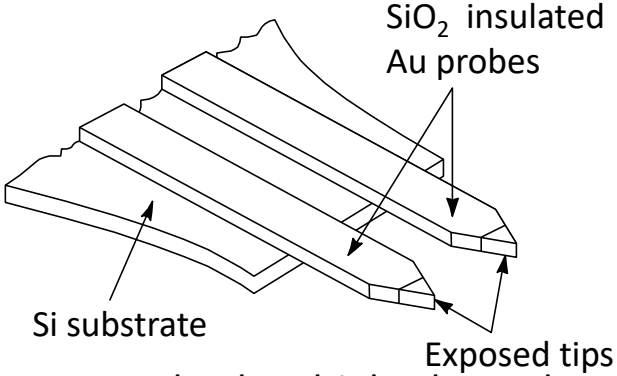
Intracellular recording – typically for recording from cells, such as cardiac myocyte

Need high impedance amplifier…negative capacitance amplifier!

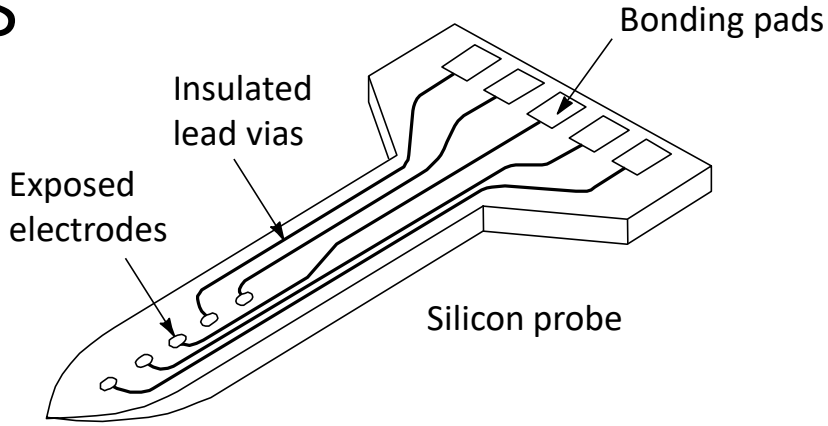
Introduction: neural microsystems



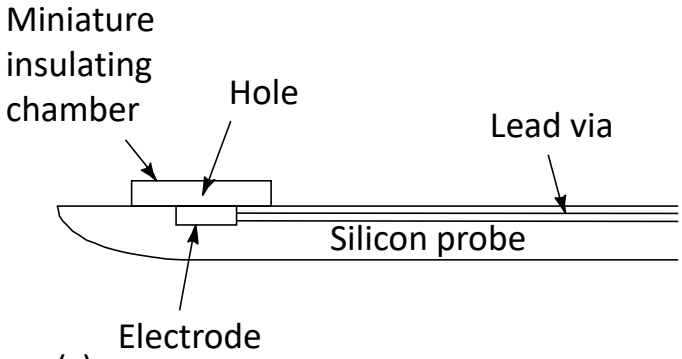
Microelectronic technology for Microelectrodes



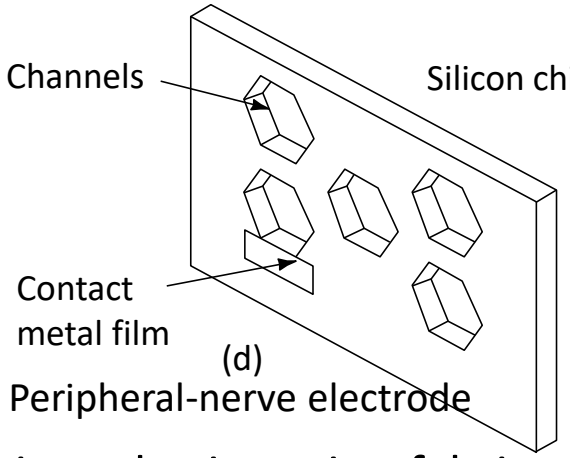
(a) Beam-lead multiple electrode.



(b) Multielectrode silicon probe



(c) Multiple-chamber electrode



(d) Peripheral-nerve electrode

Different types of microelectrodes fabricated using microfabrication/MEMS technology

Michigan Probes for Neural Recordings

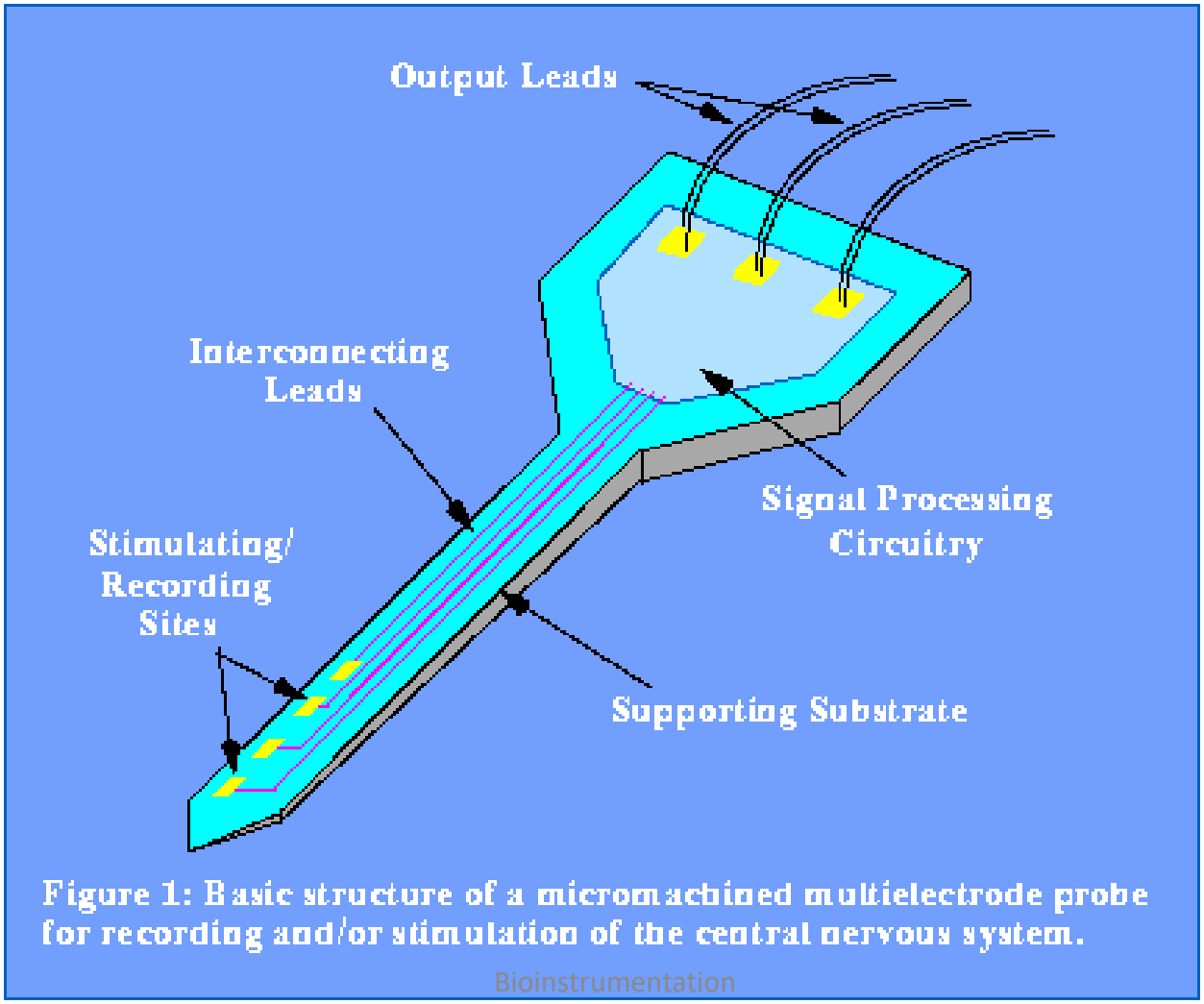
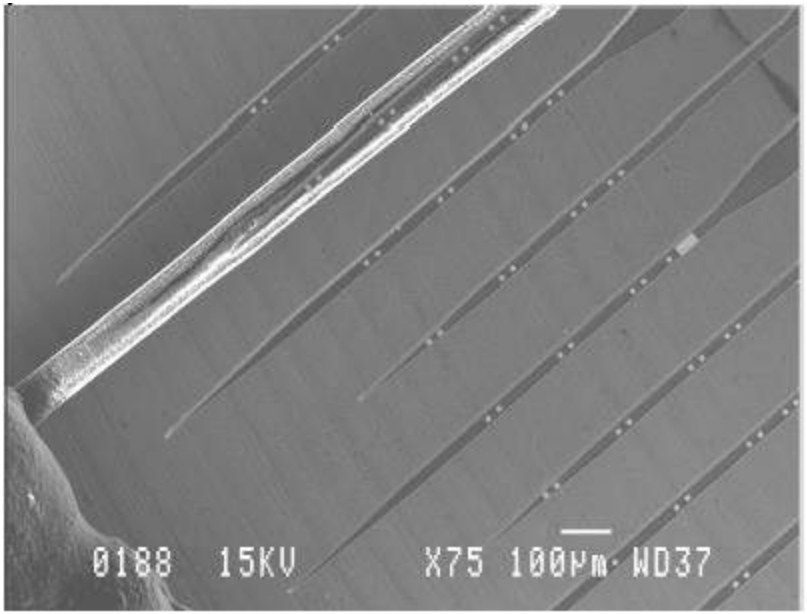
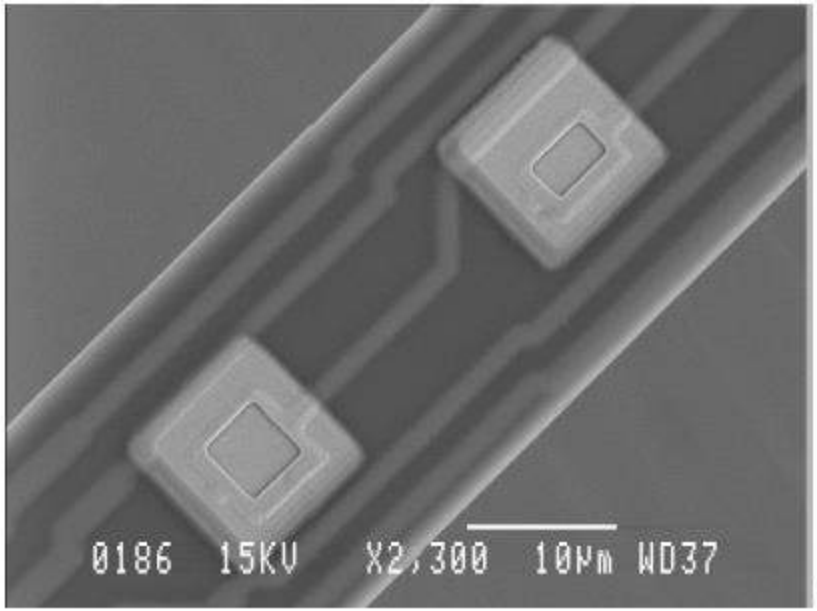


Figure 1: Basic structure of a micromachined multielectrode probe for recording and/or stimulation of the central nervous system.

Neural Recording Microelectrodes



(a)



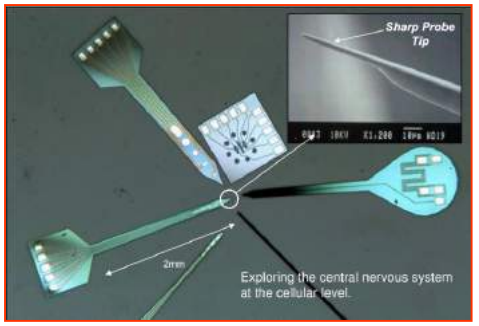
(b)

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

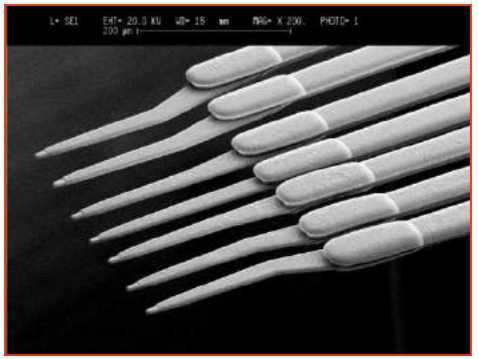
Reference :
http://www.acreo.se/acreo-rd/IMAGES/PUBLICATIONS/PROCEEDINGS/ABSTRACT-KINDLUNDH.PDF

In vivo neural microsystems: 3 examples

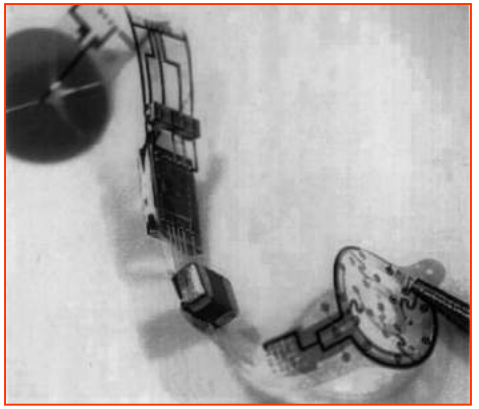
University of Michigan
Smart comb-shape microelectrode arrays for brain stimulation and recording



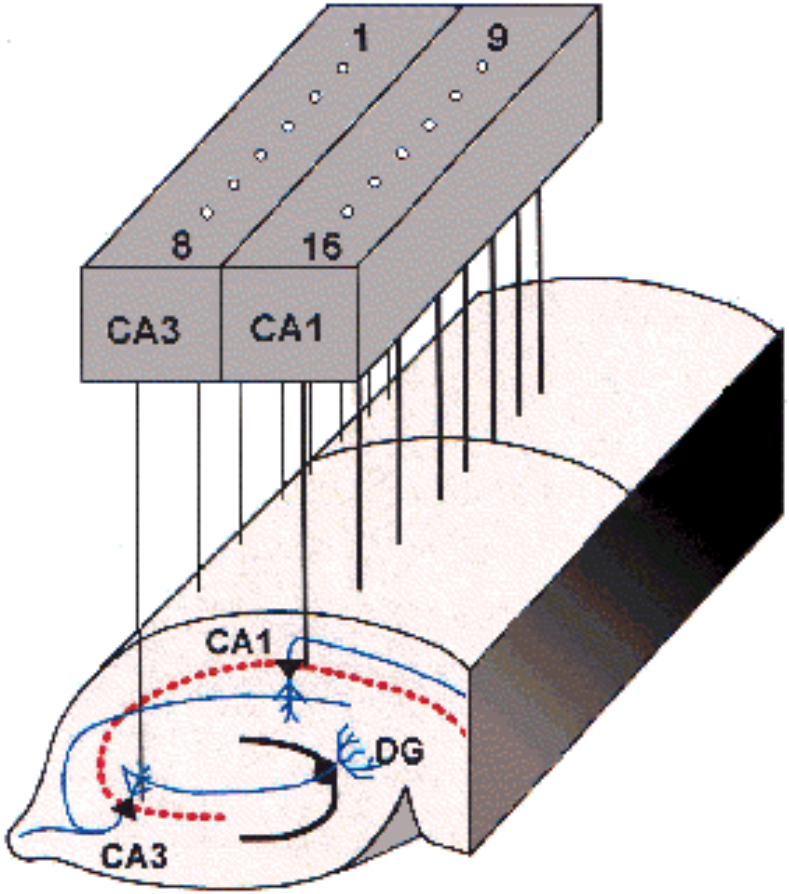
University of Illinois at Urbana-Champaign
High-density comb-shape metal microelectrode arrays for recording



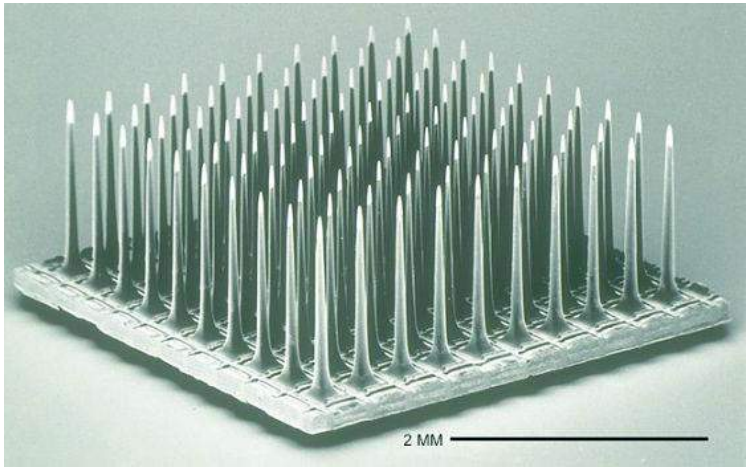
Fraunhofer Institute of Biomedical (FIBE) Engineering
Retina implant



Multi-electrode Neural Recording



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



Reference :

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

Practical Hints in Using Electrodes

- Ensure that all parts of a metal electrode that will touch the electrolyte are made of the same metal.
  - Dissimilar metals have different half-cell potentials making an electrically unstable, noisy junction.
  - If the lead wire is a different metal, be sure that it is well insulated.
  - Do not let a solder junction touch the electrolyte. If the junction must touch the electrolyte, fabricate the junction by welding or mechanical clamping or crimping.
- For differential measurements, use the same material for each electrode.
  - If the half-cell potentials are nearly equal, they will cancel and minimize the saturation effects of high-gain, dc coupled amplifiers.
- Electrodes attached to the skin frequently fall off.
  - Use very flexible lead wires arranged in a manner to minimize the force exerted on the electrode.
  - Tape the flexible wire to the skin a short distance from the electrode, making this a stress-relief point.

Practical Hints in Using Electrodes

- A common failure point in the site at which the lead wire is attached to the electrode.
  - Repeated flexing can break the wire inside its insulation.
  - Prove strain relief by creating a gradual mechanical transition between the wire and the electrode.
  - Use a tapered region of insulation that gradually increases in diameter from that of the wire towards that of the electrode as one gets closer and closer to the electrode.
- Match the lead-wire insulation to the specific application.
  - If the lead wires and their junctions to the electrode are soaked in extracellular fluid or a cleaning solution for long periods of time, water and other solvents can penetrate the polymeric coating and reduce the effective resistance, making the lead wire become part of the electrode.
  - Such an electrode captures other signals introducing unwanted noise.
- Match your amplifier design to the signal source.
  - Be sure that your amplifier circuit has an input impedance that is much greater than the source impedance of the electrodes.