

Introduction to Biomedical Instrumentation and Origin of Bioelectric Potentials

1. Biomedical Instrumentation

Biomedical instrumentation is the branch of engineering that deals with the design, development, operation and maintenance of instruments used for the diagnosis, monitoring and treatment of diseases.

Role of instruments in healthcare

Without instruments	With instruments
Patient → Symptoms → Doctor → Treatment	Patient → Symptoms → Instrument → Doctor → Diagnosis → Treatment

The instrument provides objective, measurable data, so the doctor does not rely on symptoms alone.

2. Classification of Biomedical Equipment

Type	Purpose	Examples
Diagnostic equipment	To identify diseases	ECG (detects heart abnormalities), EEG, EMG
Therapeutic equipment	To provide treatment	Pacemaker, insulin pump, ventilator

3. Block Diagram of Biomedical Instrumentation (Man–Instrument System)

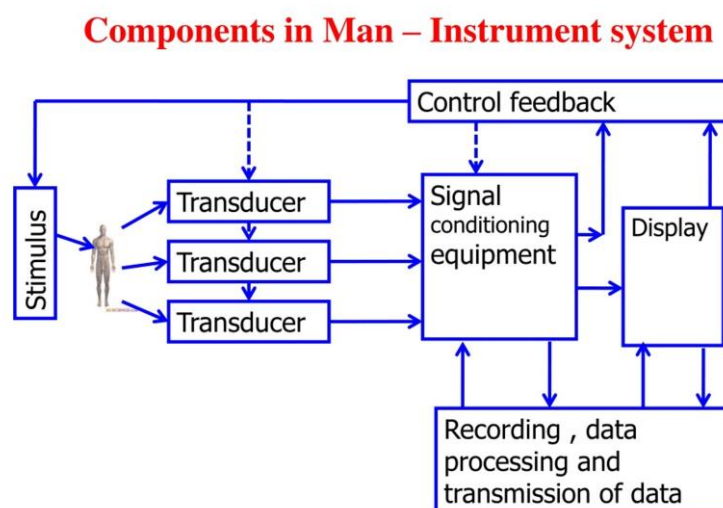


Figure 3: Components of the man–instrument system

Stage	Function	Examples
1. Stimulus	The physical quantity produced by the human body	Temperature, blood pressure, heart rate, respiration, blood glucose
2. Sensor / transducer	Converts the biological quantity into an electrical signal	ECG electrode converts ionic current into an electrical signal
3. Signal conditioning	Body signals are extremely weak (usually 10 μV – 5 mV) and contain noise, so they are amplified, filtered and isolated	Amplifier, filter, isolation stage
4. Processing	Analyses the signals	Microcontroller, DSP, computer
5. Display	Presents results; the doctor interprets them	Monitor, computer, mobile app

The block diagram also shows recording, data processing and transmission of data, and a control / feedback path to the subject (for example a stimulus applied back to the patient).

4. Measurement: In Vivo and In Vitro

Type	Meaning	Example
In vivo	Measurement made on or within the human body	A device inserted into the bloodstream to measure the pH of blood
In vitro	Measurement performed outside the body	Measuring blood pH from a blood sample

5. Physiological Systems

A physiological system is a group of organs working together to perform a specific body function. Each system has measurable parameters:

System	Typical measurements
Cardiovascular	Blood pressure, ECG, heart rate, blood flow
Respiratory	Respiration rate, oxygen saturation, CO ₂ , spirometry
Nervous	EEG, nerve conduction, brain waves
Muscular	EMG
Digestive	pH, temperature, pressure
Endocrine	Blood glucose, hormone levels
Renal	Urine output, electrolytes, creatinine

6. Origin of Bioelectric Potentials

- The systems of the body generate their own monitoring signals while performing their functions, and these signals carry useful information about how the system is working.
- Bioelectric potentials are ionic voltages produced by the electrochemical activity of certain cells.
- Transducers (electrodes) convert these ionic potentials into electrical signals.
- Cells covered by a semi-permeable membrane and surrounded by ionic body fluids can produce bioelectric potentials. Such cells are called excitable cells, e.g. nerve cells and muscle cells.
- The membrane lets some substances pass and keeps others out. The body fluids are conductive solutions containing charged atoms called ions.
- Sodium (Na^+), potassium (K^+) and chloride (Cl^-) ions play the major role.

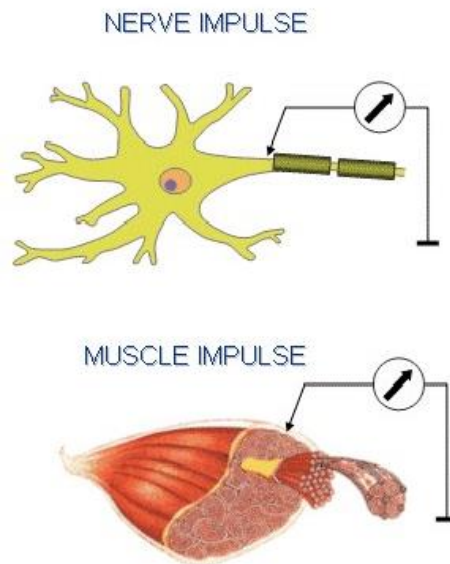


Figure 4: Nerve impulse and muscle impulse – bioelectric activity recorded from excitable cells

Cell membrane

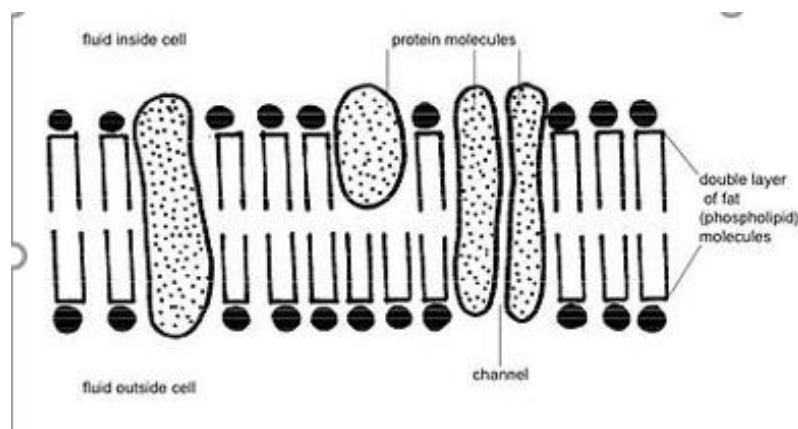


Figure 5: Cell membrane – phospholipid bilayer with protein molecules and ion channels (fluid inside and outside the cell)

The membrane has two states of activity: the resting state and the action state.

7. Resting Potential

- The membrane of an excitable cell permits entry of K^+ and Cl^- ions but largely blocks Na^+ .
- The concentration of Na^+ is higher outside the membrane than inside.
- As a result, in the resting state the inner surface of the membrane is negative and the outer surface is positive – the inside of the cell is more negative than the outside.
- This membrane potential is called the resting potential. It is measured from inside the cell with respect to the body fluids, so it is negative.
- Range: -60 mV to -100 mV (example on the slide: -90 mV).
- A cell in the resting state is said to be polarised.

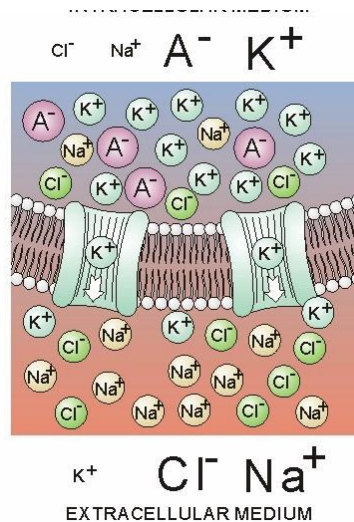


Figure 7: Distribution of K^+ , Cl^- , Na^+ and large anions (A^-) across the membrane

Equilibrium potential – Nernst equation

For each ion, diffusion (from high to low concentration) is balanced by the electric field across the membrane. At the point where the two balance, the equilibrium potential is reached. It is calculated with the Nernst equation at body temperature (37°C).

8. Depolarisation

1. When the cell is excited or stimulated, the membrane changes its characteristics.
2. Sodium ions rush into the cell.
3. At the same time potassium ions try to move out.
4. After an equilibrium state is reached, the sodium is moved back outside and the resting condition is restored.

Definition

Depolarisation: when the cell is excited or stimulated, the outer side of the cell membrane becomes momentarily negative with respect to the interior.

9. Cell Potential Waveform and Action Potential

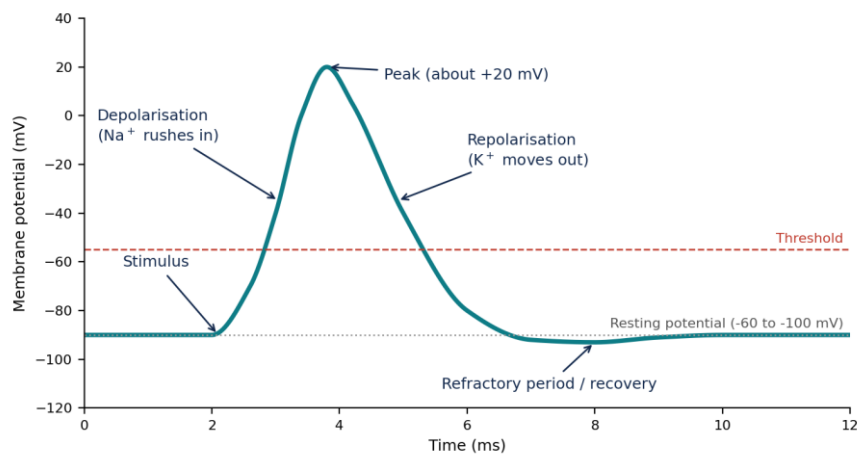


Figure 8: Schematic action potential (drawn for these notes; values from the lecture slides)

- The wave of excitation travelling along a muscle causes it to contract. The contraction wave always follows the excitation wave because its velocity is lower.
- This occurs in skeletal muscle, heart muscle and smooth muscle.
- Every contraction of a muscle produces an electric voltage. The moving muscle section is always negative with respect to its surroundings.
- These voltages are called action potentials, because they are generated by the action of the muscles. The slides give about 20 mV for the action potential.

10. Propagation of Action Potentials

- When a cell is excited and generates an action potential, ionic currents flow.
- These currents excite neighbouring cells or the adjacent area of the same cell, so the action potential travels.
- Conduction velocity is the rate at which an action potential moves down a fibre or is passed from cell to cell. It is also called the nerve conduction rate.

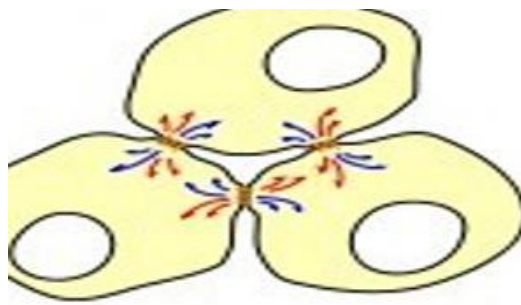


Figure 9: Excitation passing between adjacent cells

11. Biopotential States – Definitions

Term	Definition
Biopotential	An electric potential measured between points in living cells, tissues and organisms, which accompanies all biochemical processes

Term	Definition
Resting potential	The potential produced by unequal charge distribution across the membrane of a living cell at rest (-60 to -100 mV). The cell is said to be polarised
Action potential	Potential produced when the wave of excitation propagates in the muscle and causes contraction; the active region becomes negative (about 20 mV on the slides)

12. Measurement of Bioelectric Potentials

- A transducer is required to measure bioelectric potentials.
- Electrical signals produced by body activities are used for monitoring and diagnosis.
- To measure and record these potentials (and hence currents), an interface between the body and the electronic measuring apparatus is needed – this is the electrode (see the Bioelectrodes notes).

13. Stimulus Threshold and Refractory Period

- Bioelectric currents are due to positive and negative ion movement in a conductive fluid. Ions have finite mass and meet resistance, so they move at limited speeds.
- Therefore the action potential has a finite rise time and fall time.
- Stimulus threshold: unless a stimulus above a certain minimum value is applied, the cell is not depolarised and no action potential is generated.
- Refractory period: after stimulation, a finite time is needed for the cell to return to its pre-stimulus state, because the energy of the action potential comes from metabolic processes that take time to complete. During this time the cell cannot respond normally to a new stimulus.

14. All-or-None Law

Whatever the method of excitation or the strength of the stimulus, the action potential is always the same for a given cell.

A stimulus below threshold gives no response; a stimulus at or above threshold gives the full response. A stronger stimulus does not make a bigger action potential.