Biomedical Instrumentation Module

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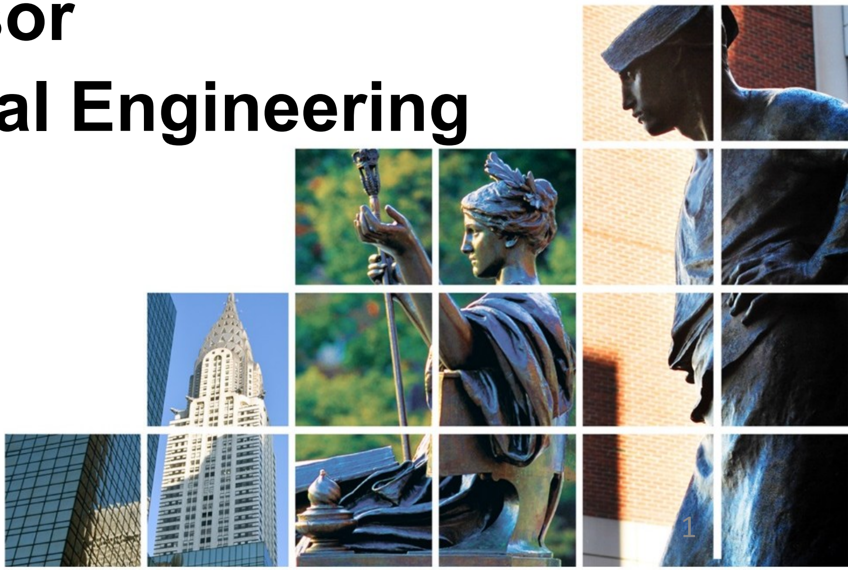
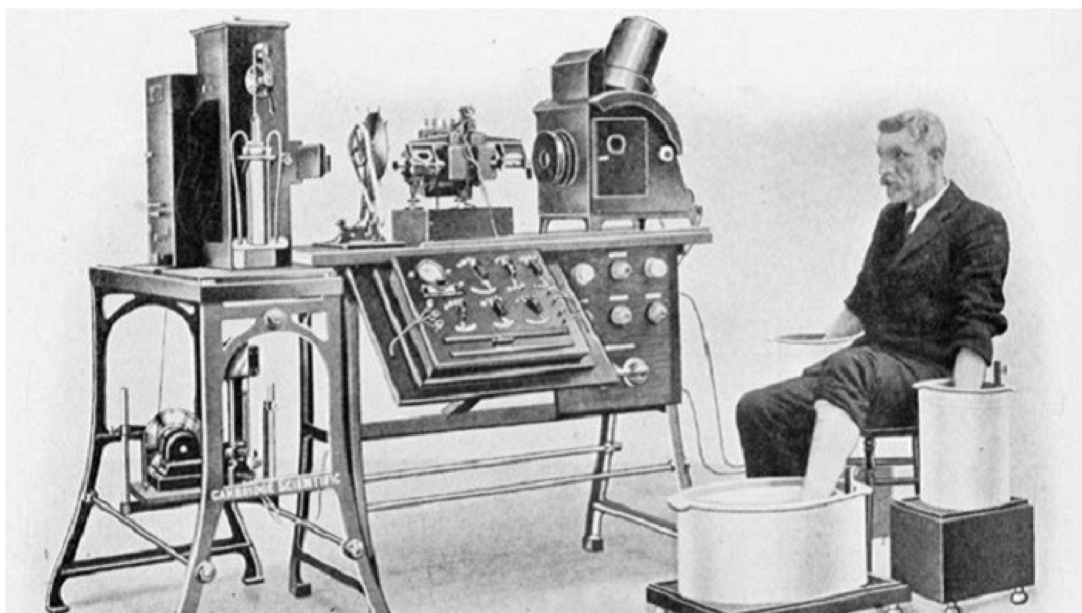
COLUMBIA | ENGINEERING
The Fu Foundation School of Engineering and Applied Science



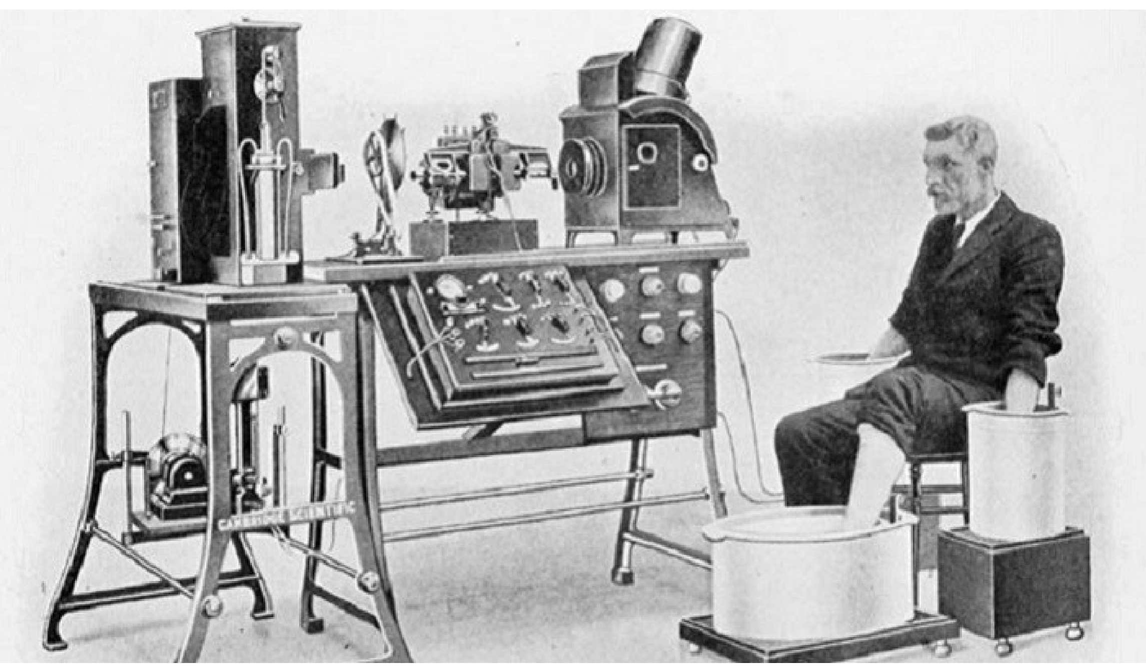
Electrocardiogram (ECG or EKG)

- Willem Einthoven placed the arm and leg of a patient into two jars of salt water and attached the water to the ends of a silver wire, which was suspended in a strong magnetic field.
- The suspended silver wire moved rhythmically as the man’s heart beats.



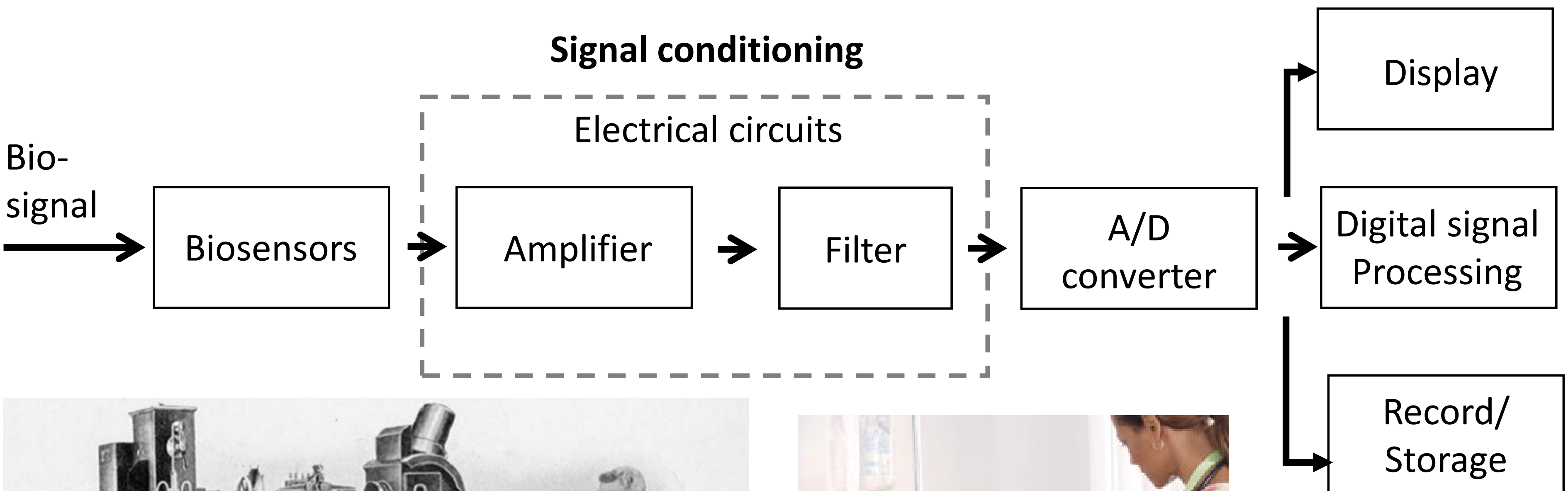
ECG

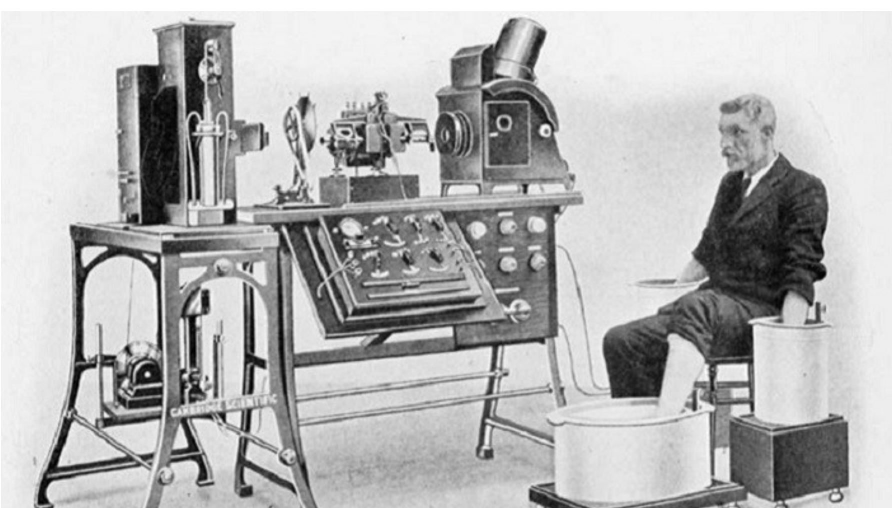
- By projecting a tiny light beam across the silver wire, Einthoven was able to record the movement of the wire as waves on a scroll of moving photographic paper



Biomedical instrumentation

- **Biomedical devices usually have multiple components**





Biomedical sensors

- Many biomedical instruments use a transducer or sensor to convert a signal created by the body into an electric signal. Strictly speaking
  - A **sensor** is a device that converts a physical signal and its variation into an electrical signal.
  - A **transducer** is a device that converts one type of physical signal into another type of physical signal.
- ECG, EEG,…

Measurement of physical properties

Biosignals:

- Temperature
- Force
- Pressure
- Flow
- Position
- Electrical potential
- …

Sensor specifications

- **Active sensor:**
  - Requires an external source of excitation.
  - For example, resistance-based sensors are active sensors, because a current must be passed through them and the corresponding voltage will be measured in order to determine the resistance value.
- **Passive sensor:**
  - Generates its own electrical output signal without requiring external voltages or currents.
  - For example, thermocouples are passive sensor because it generates an electrical voltage

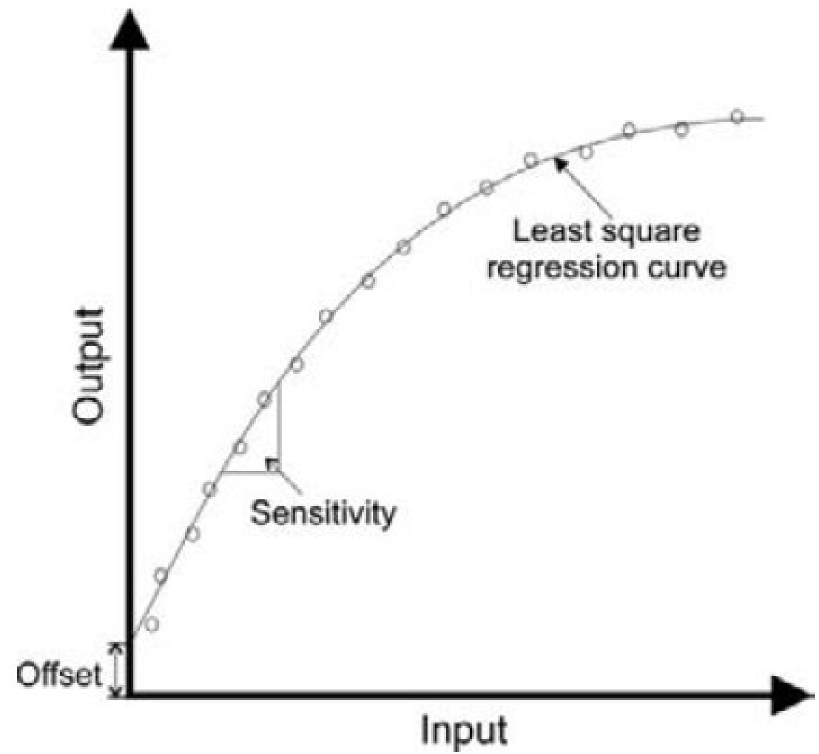
Sensor specifications

- Sensitivity: the ratio of output change to a given change in input.
- A high sensitivity implies that a small change in input quantity causes a large change in its output.

A temperature sensor

A: 35-45 °C -> 0-10V

B: 0-100 °C -> 0-10V



Resolution

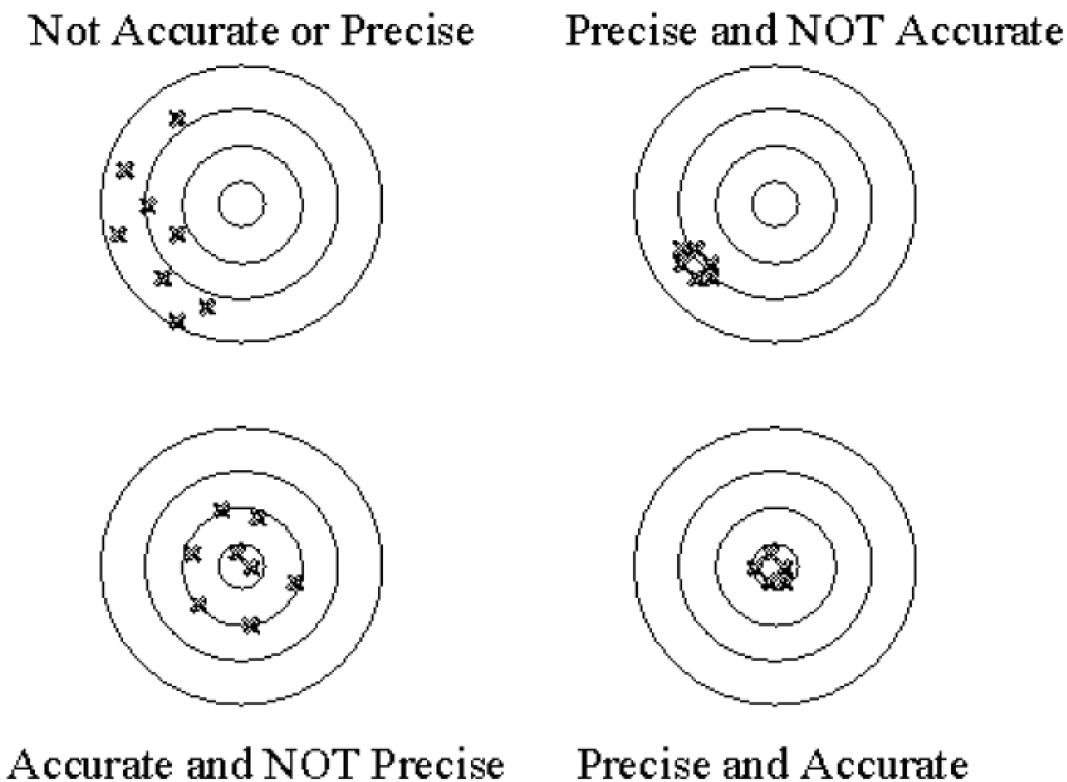
- When the input quantity is increased from some arbitrary nonzero value, the output of a sensor may not change until a certain input increment is exceeded.
- Accordingly, resolution is defined as the smallest distinguishable input change that can be detected with certainty.

Range

- The range of a sensor corresponds to the minimum and maximum operating limits during which the sensor is expected to measure accurately.
- For example, a temperature sensor may have a nominal performance over an operating range of -20 to +100°C

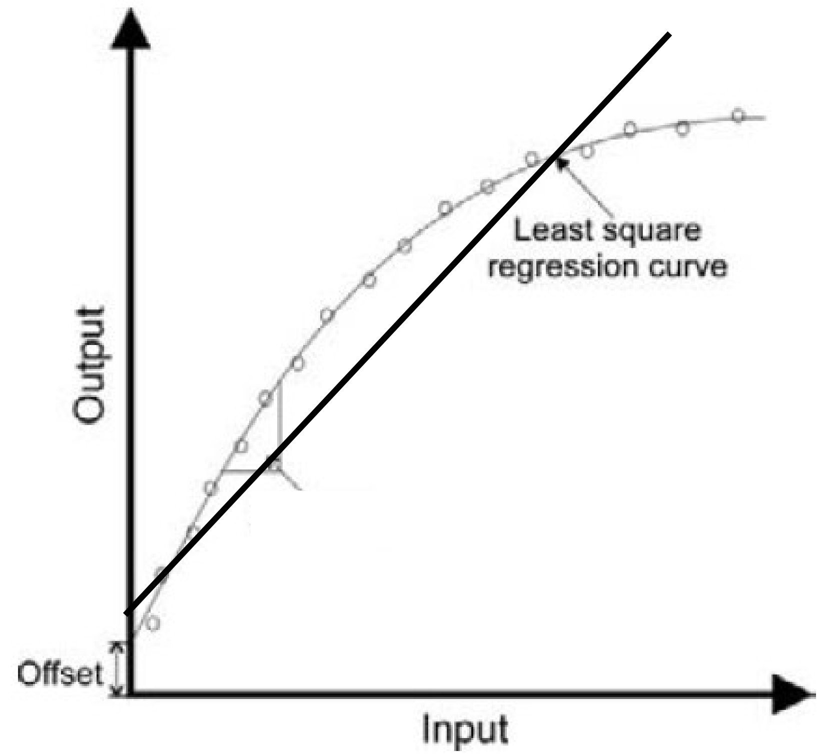
Accuracy & Precision

- Accuracy refers to the difference between the true value and the value measured by the sensor.
- Precision refers to the degree of measurement reproducibility



Linearity

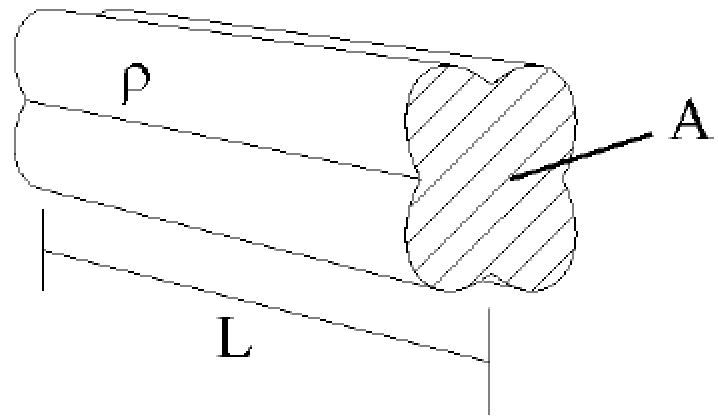
- Linearity is a measure of the maximum deviation of any reading from a straight calibration line, which is typically defined by the least-square regression fit of the input versus output relationship.
- Typically, sensor linearity is expressed as either a percent of the actual reading or a percent of the full-scale reading.



Variable-resistive sensors

- The resistance of an electrical conductor is

$$R = \frac{\rho L}{A}$$



Where:

R is resistance
L is the length of the conductor
A is the cross-sectional area of the conductor
ρ is the resistivity of the material

Strain gages

- One of the most common displacement transducer (strain -> change in resistance)
- Strain, or axial strain, is defined as the fractional change in length in response to applied force:

$$\varepsilon = \frac{\Delta L}{L}$$

Strain gages

- What the relationship between ΔR and ε?

$$dR = d\left(\frac{\rho L}{A}\right) = \frac{\rho}{A} dL + \frac{L}{A} d\rho - \frac{\rho L}{A^2} dA$$

↓

$$\frac{dR}{R} = \frac{dL}{L} + \frac{d\rho}{\rho} - \frac{dA}{A}$$

Strain gages

- Poisson's ratio defines the relationship between the change in diameter of a body experiencing uniaxial stress and change in length

$$\nu = -\frac{\Delta D}{D} / \frac{\Delta L}{L}$$

Minus sign means that increase in diameter results in decrease in length

Strain gages

- For a circular wire, the cross-sectional area

$$A = \pi(\frac{D}{2})^2$$

$$dA = d(\pi(\frac{D}{2})^2) = \pi(\frac{D}{2})dD$$

$$\frac{dA}{A} = \frac{\pi(\frac{D}{2})dD}{\pi(\frac{D}{2})^2} = 2\frac{dD}{D} = -2\nu\frac{dL}{L}$$

Strain gages

$$\frac{dR}{R} = (1 + 2\nu)\frac{dL}{L} + \frac{d\rho}{\rho}$$

Dimensional effect

Piezoresistive effect: resistance change due to changes in the lattice structure of the material induced by strain

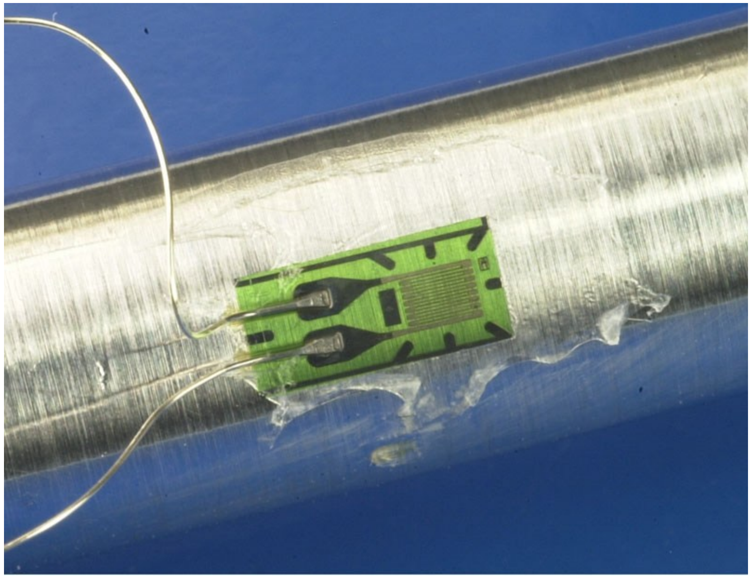
Strain gages

- The gage factor G

$$G = \frac{\Delta R / R}{\Delta L / L} = (1 + 2\nu) + \frac{\Delta\rho / \rho}{\Delta L / L}$$

- The gage factor for most metals is primarily a function of dimensional effects, i.e. $G = (1 + 2\nu)$
- The larger the gage factor, the better.

Strain gages



- The strain and change in resistance

$$\varepsilon = \frac{1}{G}\frac{\Delta R}{R}$$

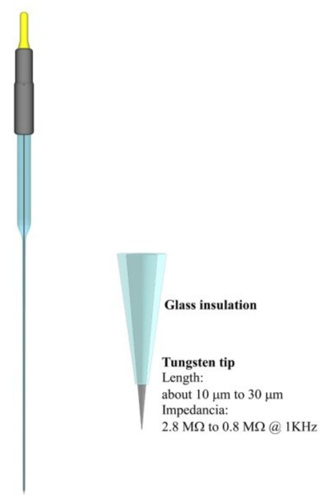
- Strain of material is typically very small
- A typical strain gage has G = 2, R=300 Ohm, given a strain of 0.000001, the change in resistance is

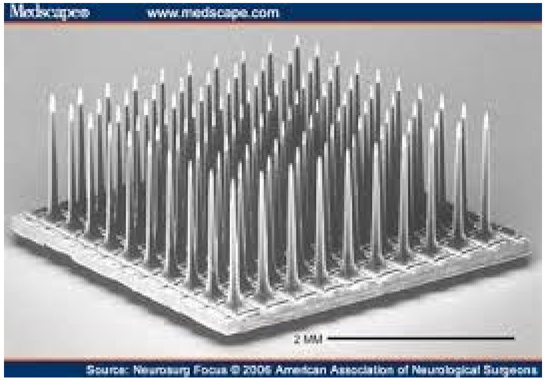
$$\Delta R = \varepsilon G R = 600\,\mu\Omega$$

Too small to measure using a multimeter!

Electrodes

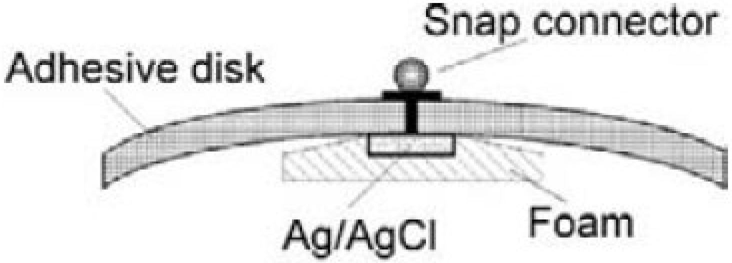
- Are used to measure biopotentials
- The function of these recording electrodes is to couple the ionic potentials generated inside the body to an electronic instrument.
- Biopotential electrodes are classified either as noninvasive (skin surface) or invasive (e.g., microelectrodes or wire electrodes).





ECG Electrodes

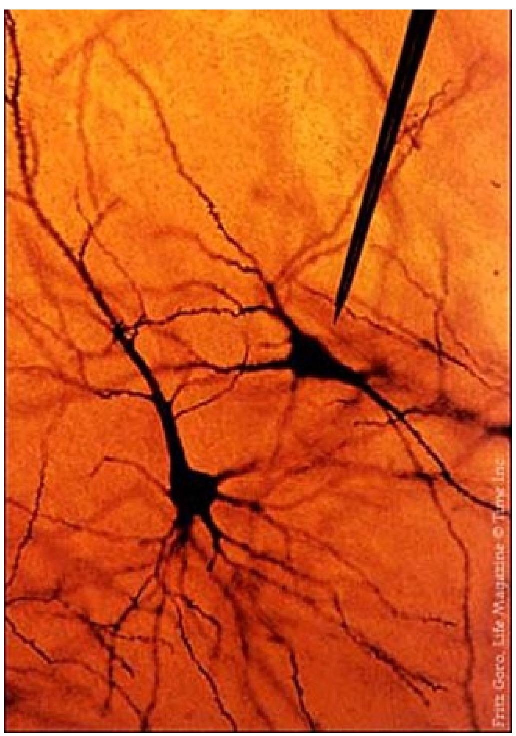
- A typical ECG electrode is the silver/silver chloride electrode (Ag/AgCl), which is formed by electro-chemically depositing a very thin layer of silver chloride onto a silver electrode
- These electrodes are recessed from the surface of the skin and embedded in foam that has been soaked with an electrolyte paste to provide good electrical contact with the skin, and to reduce motion artifacts



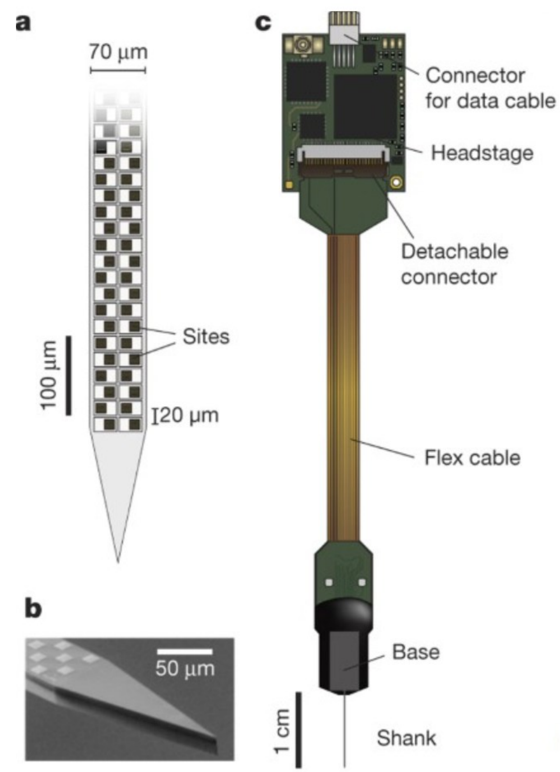
Microelectrodes

- They are thin sharp electrodes made of stiff metal, such as tungsten, to record from single neurons in the brain or nervous system.

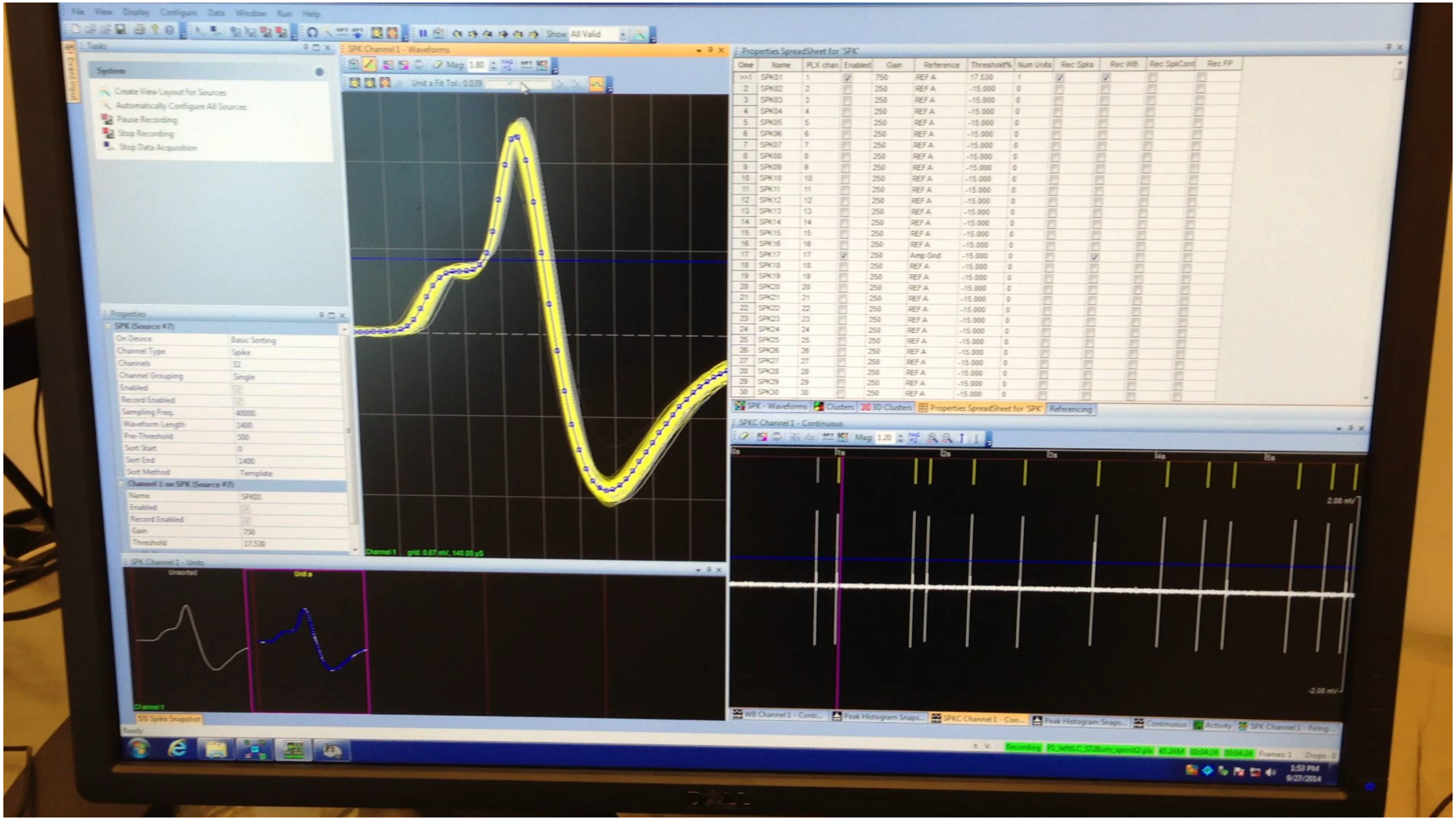
Tungsten metal electrode



Silicone electrode

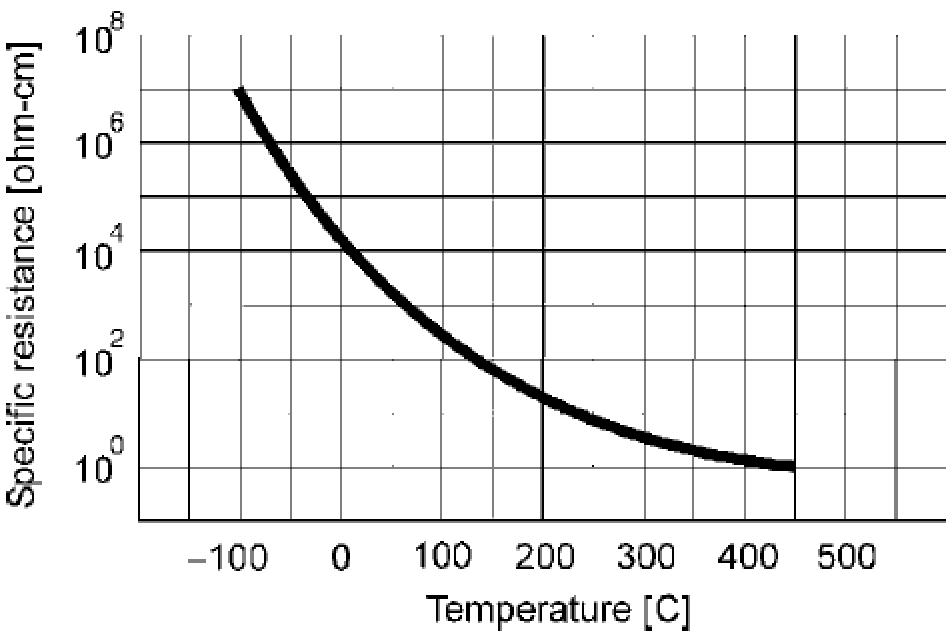


Spiking activity



Thermistors

- Thermistors are temperature-sensitive transducers made of compressed sintered metal oxides (such as nickel, or cobalt) that change their resistance with temperature
- Resistance-temperature relationship is typically ***non-linear***

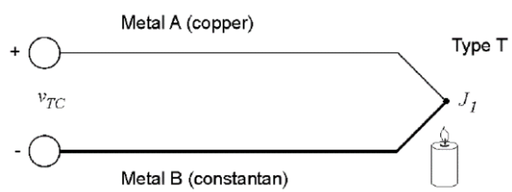


$$R_T = R_0 \times \exp\left[\beta \times \left(\frac{1}{T} - \frac{1}{T_0}\right)\right]$$

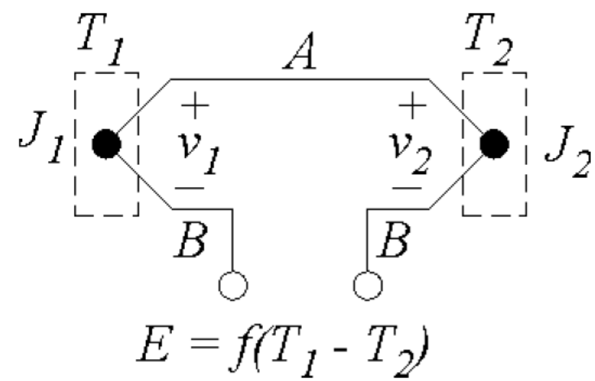
Where: R_0 is resistance at T_0
Beta: Material constant

Thermocouples

- Thermocouples: voltage exist across a junction of two dissimilar metals, discovered by Seebeck in 1821



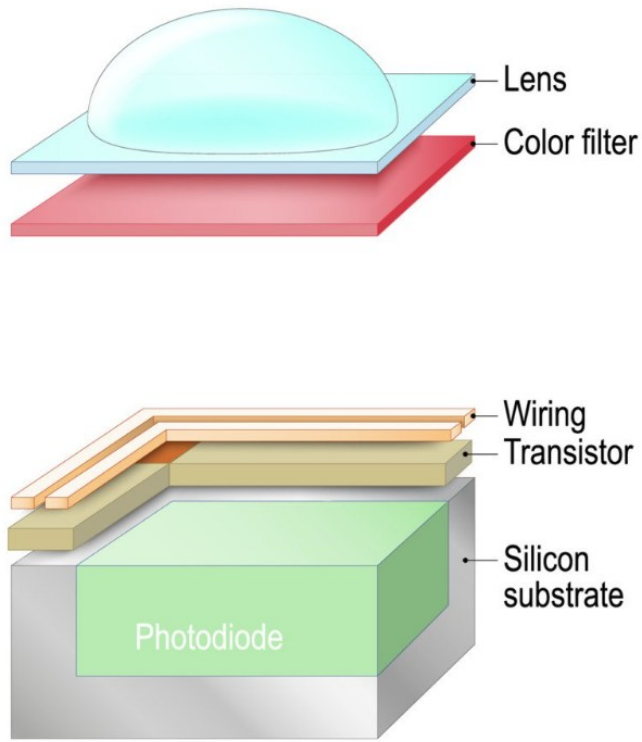
$$\Delta E = -S(T)\Delta T$$



- Precise thermocouple measurement circuits have no fewer than two thermocouple junctions.
- Thus, what is represented by *E* is the temperature difference between the two junctions, not the absolute temperature of one junction.

Image sensors

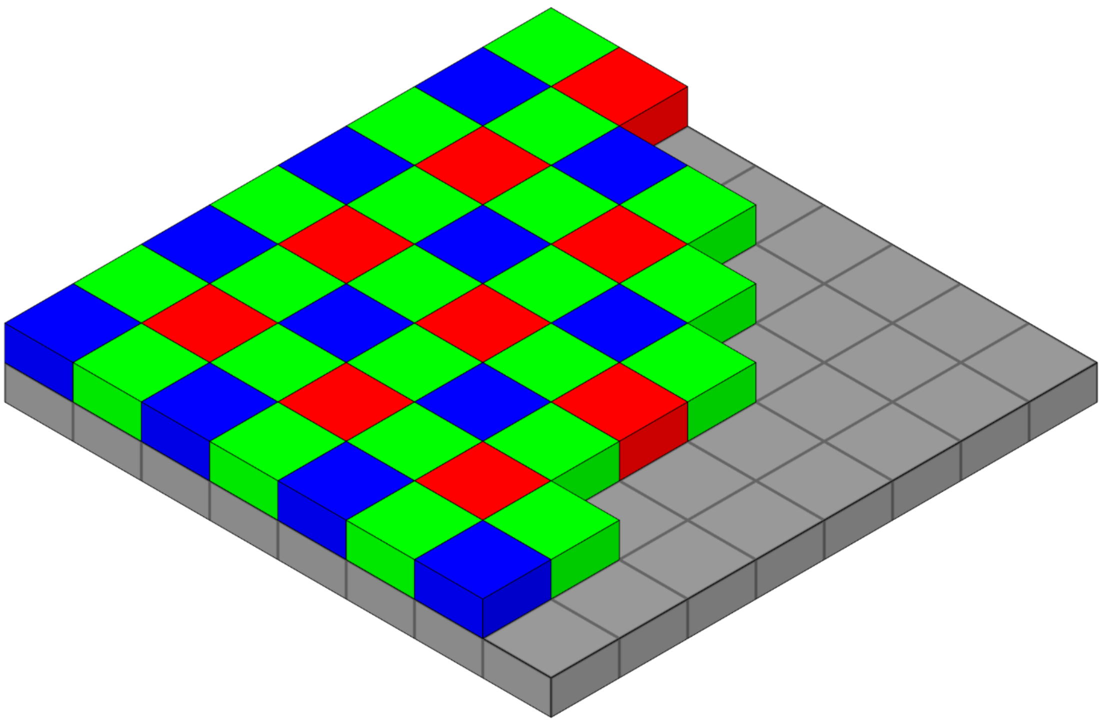
- A 2D array of photodiodes, with each photodiode covered with a microlens and color filter.



https://petapixel.com/what-is-ccd-cmos-sensor/

Color filter array

- RGB Bayer mosaic: a color filter array (CFA) for arranging RGB color filters on a square grid of photosensors



https://en.wikipedia.org/wiki/Bayer_filter

CCD and CMOS sensors

- CCD: **C**harge **C**oupled **D**evice
- CMOS: **C**omplementary **M**etal **O**xide **S**emiconductor
- CMOS sensors are more popular because they are made with computer-chip technology, so each pixel has its own amplifier.
- CMOS sensors are generally cheaper and faster compared to CCD sensors.