Sensor Design III – Other sensors

ME490A/B
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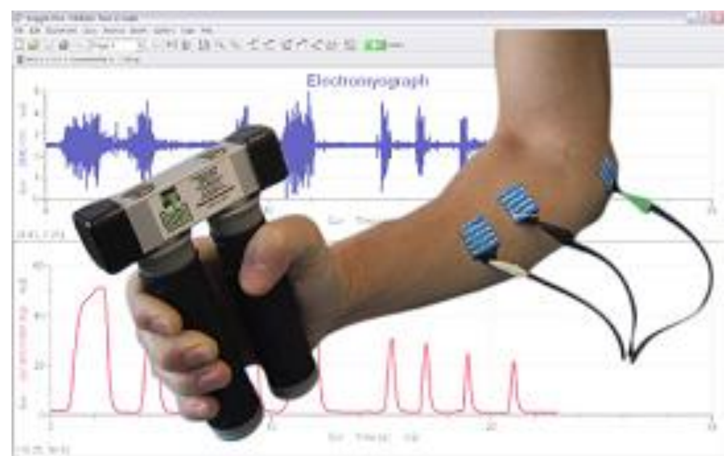
4 28 95

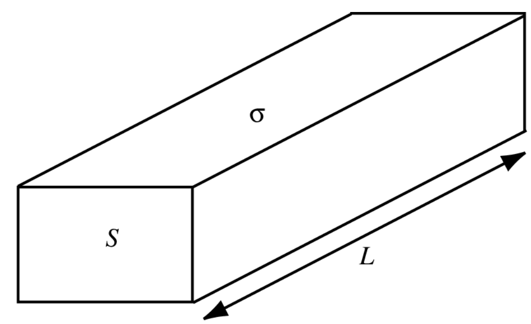

31.4°c


37.0°c
ESTAR


Electromyograph

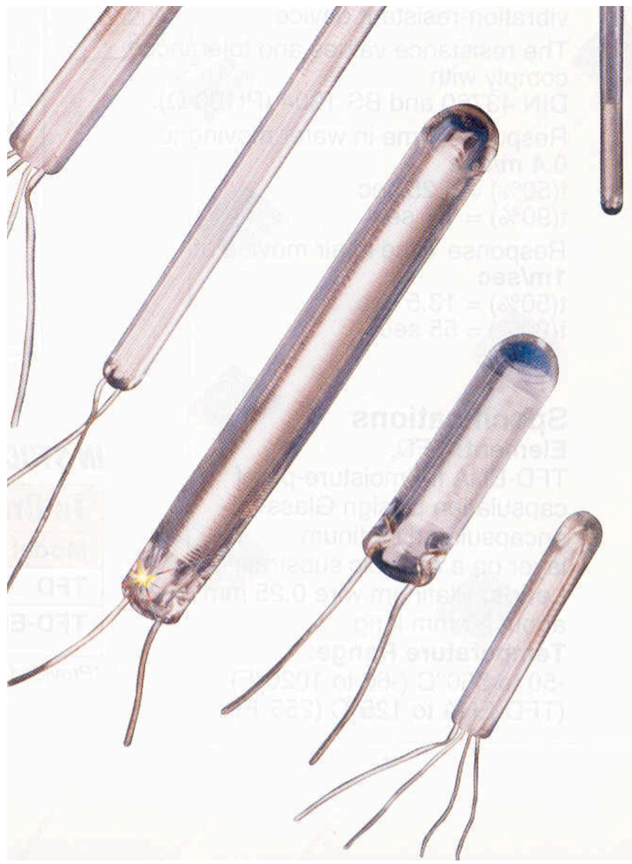
Thermoresistive effect

- Conductivity depends on temperature
- Conductors and semiconductors
- Resistance is measured, all other parameters must stay constant.



$$R = \frac{L}{\sigma S}$$

Glass encapsulated RTDs



Construction (cont.)

- Materials:
- Platinum - used for precision applications
  - Chemically stable at high temperatures
  - Resists oxidation
  - Can be made into thin wires of high chemical purity
  - Resists corrosion
  - Can withstand severe environmental conditions.
  - Useful to about 800 °C and down to below –250°C.
  - Very sensitive to strain
  - Sensitive to chemical contaminants
  - Wire length needed is long (high conductivity)

Construction (cont.)

- Materials:
- Nickel and Copper
  - Less expensive
  - Reduced temperature range (copper only works up to about 300°C)
  - Can be made into thin wires of high chemical purity
  - Wire length needed is long (high conductivity)
  - Copper is not suitable for corrosive environments (unless properly protected)
  - At higher temperatures evaporation increases resistance

Silicon Resistive Sensors

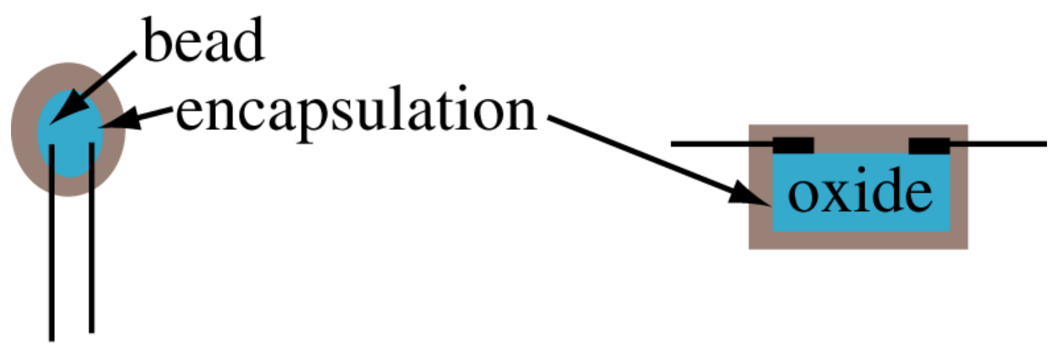
- Conduction in semiconductors
- Valence electrons
  - Bound to atoms in outer layers (most electrons in pure semiconductors)
  - Can be removed through heat (band gap energy)
  - When removed they become conducting electrons (conduction band)
  - A pair is always released - electron and hole
- Conductivity of semiconductors is temperature dependent
  - Conductivity increases with temperature
  - Limited to a relatively small temperature range

Thermistors

- Thermistor: **Therm**al res**istor**
- Became available: early 1960's
- Based on oxides of semiconductors
  - High temperature coefficients
  - NTC
  - High resistances (typically)

Construction

- Beads
- Chips
- Deposition on substrate



Epoxy encapsulated bead thermistors

Thermistors - properties

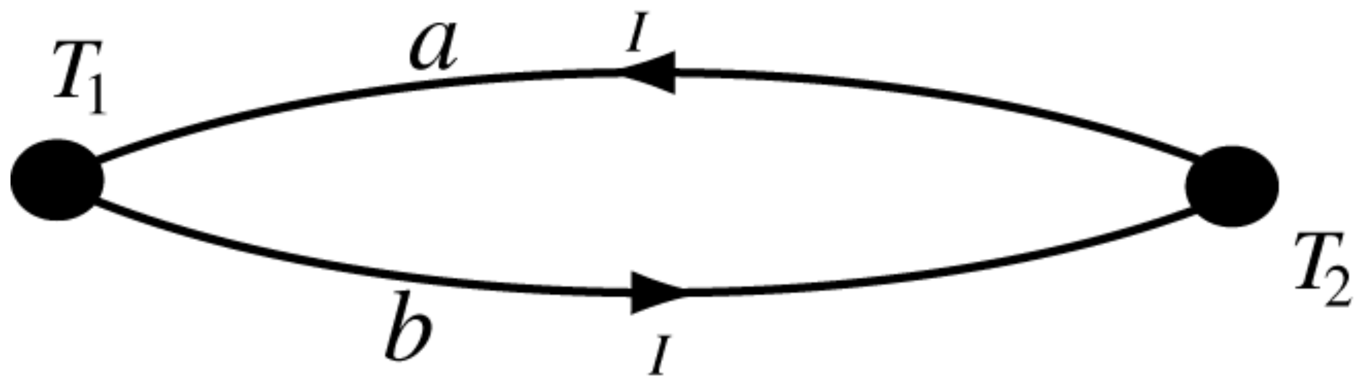
- Self heating errors as in RTDs but:
  - Usually lower because resistance is higher
  - Current very low (R high)
  - Typical values: 0.01°C/mW in water to 1°C/mW in air
- Wide range of resistances up to a few MΩ
- Can be used in self heating mode
  - To raise its temperature to a fixed value
  - As a reference temperature in measuring flow
- Repeatability and accuracy:
  - 0.1% or 0.25°C for good thermistors

Thermistors - properties

- Temperature range:
  - -50 °C to about 600 °C
  - Ratings and properties vary along the range
- Linearity
  - Very linear for narrow range applications
  - Slightly nonlinear for wide temperature ranges
- Available in a wide range of sizes, shapes and also as probes of various dimensions and shapes
- Some inexpensive thermistors have poor repeatability - these must be calibrated before use.

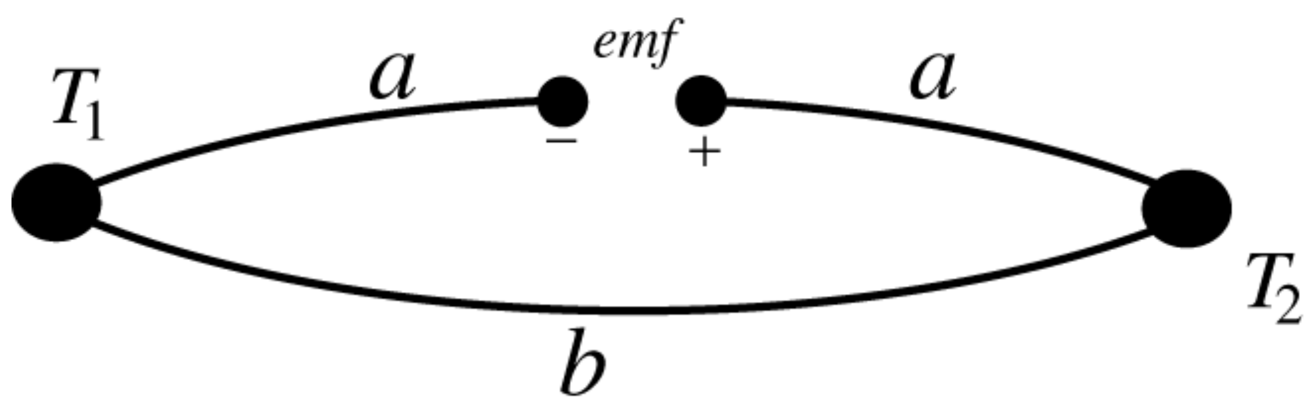
The Seebeck effect

- If both ends of the two conductors are connected and a temperature difference is maintained between the two junctions, a thermoelectric current will flow through the closed circuit (generation mode)



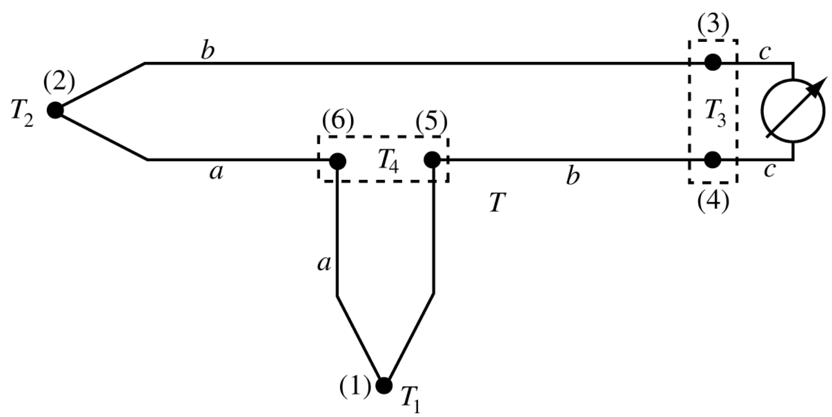
The Seebeck effect

- If the circuit is opened an emf will appear across the open circuit (sensing mode). It is this emf that is measured in a thermocouple sensor.



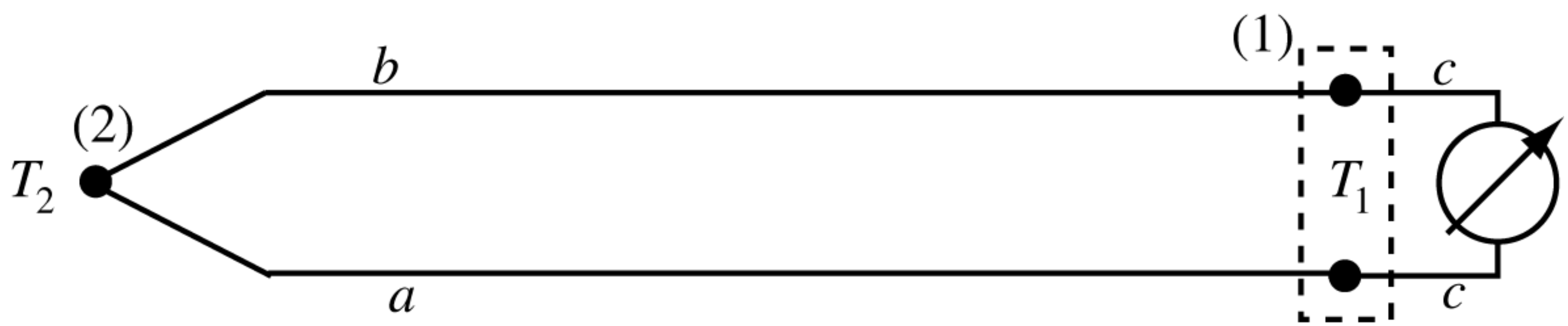
Thermocouples: connection

- Based on the thermoelectric laws:
- Usually connected in pairs
  - One junction for sensing
  - One junction for reference
  - Reference temperature can be lower or higher than sensing temperature



Connection without reference

- The connection to a voltmeter creates two junctions
  - Both are kept at temperature T_1
  - Net emf due to these junctions is zero
  - Net emf sensed is that due to junction (2)
  - This is commonly the method used



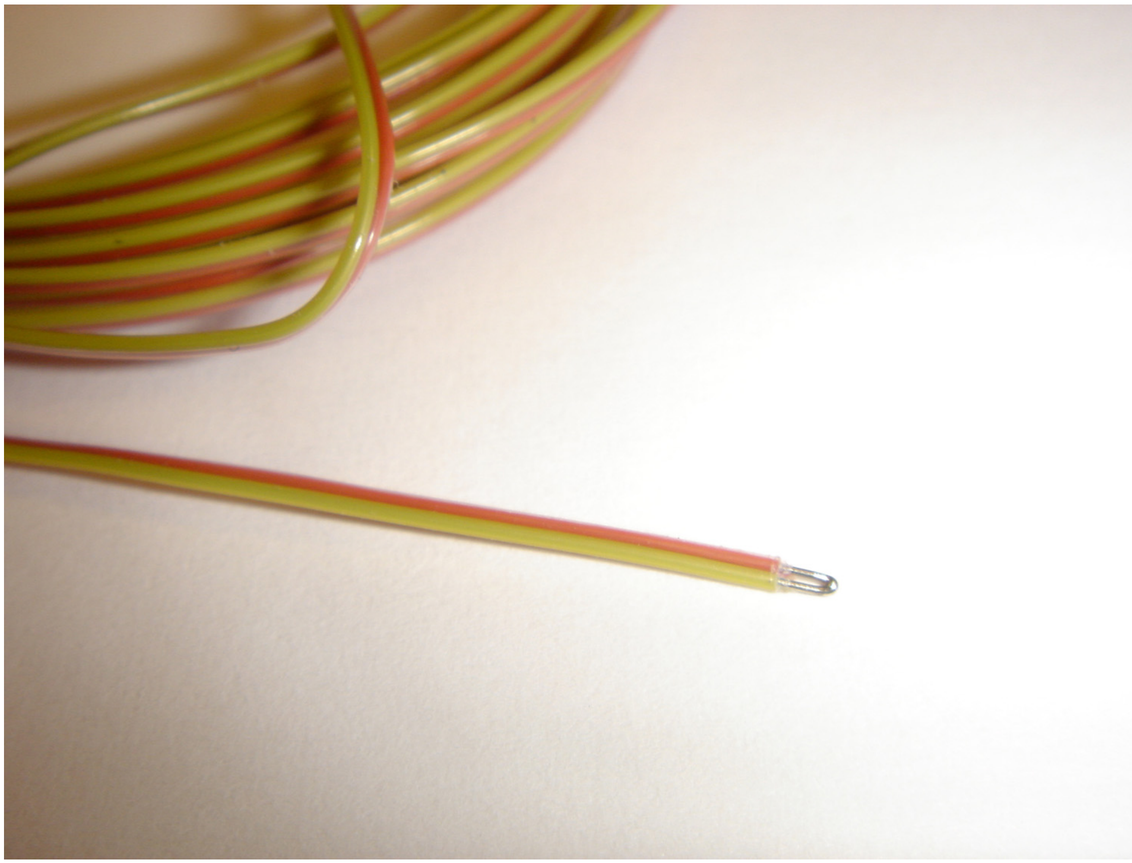
Reference junctions

- Reference junctions must be at constant, known temperatures. Examples:
- Water-ice bath (0°C)
- Boiling water (100°C)
- Any other temperature if measured
  - A separate, non-thermocouple sensor
  - The output compensated based on this temperature from Seebeck coefficients

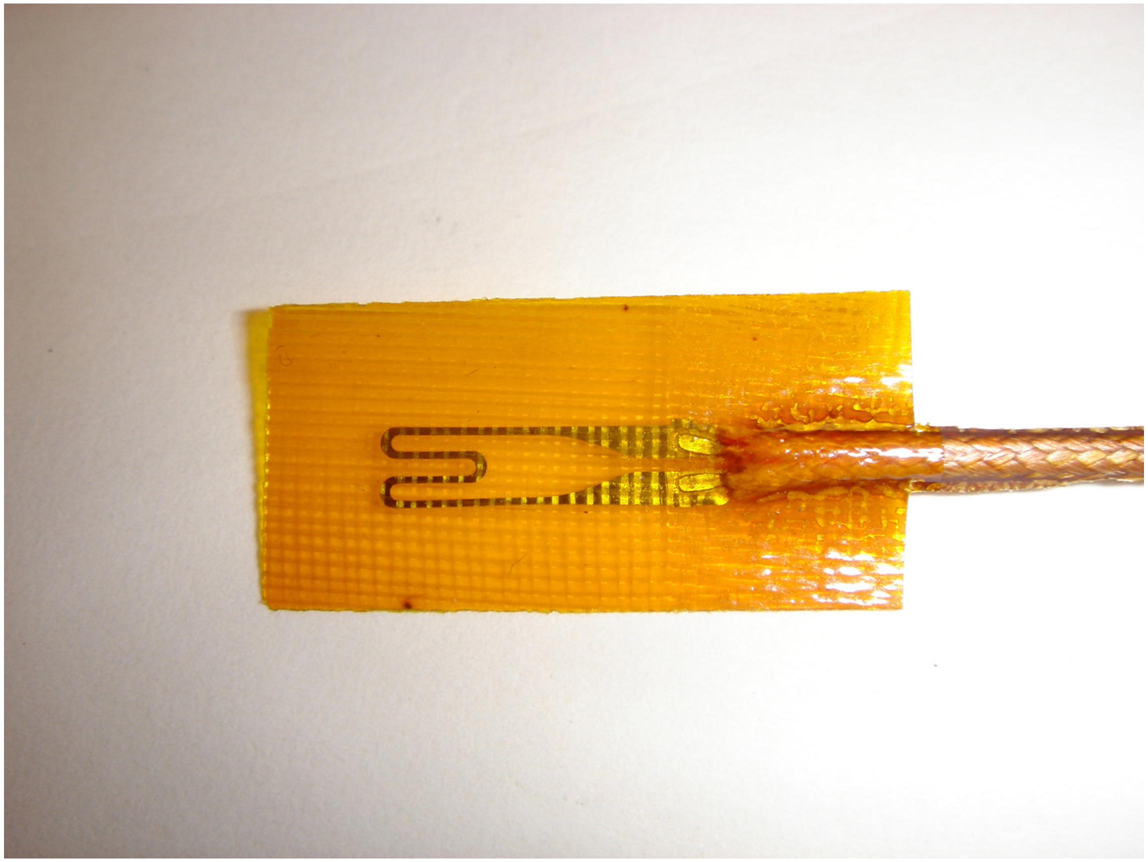
Thermocouples - practical considerations

- Choice of materials for thermocouples. Materials affect:
  - The output emf,
  - Temperature range
  - Resistance of the thermocouple.
- Selection of materials is done with the aid of three tables:
  - Thermoelectric series table
  - Seebeck coefficients of standard types
  - Thermoelectric reference table

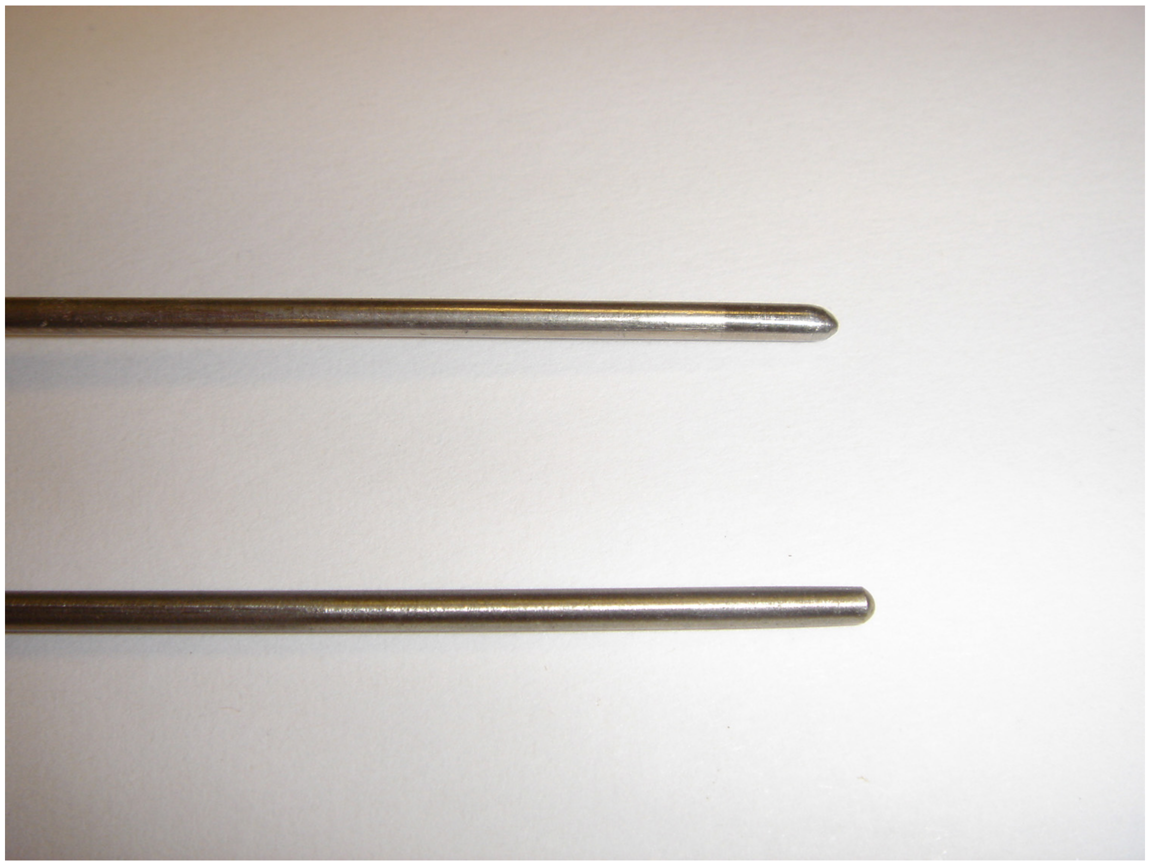
Thermocouple (exposed junction)



Thermocouple (flexible, to be cemented to surface)



Thermocouple (protected junction)

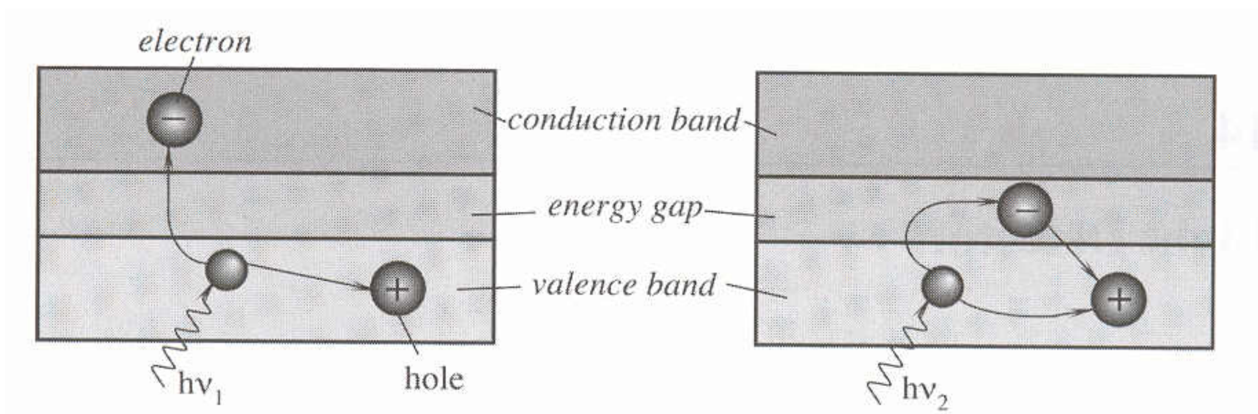


Semiconductor thermocouples

- Semiconductors have highest Seebeck coefficients
- Typical values are about 1mV/°C
- Junctions between n or p type semiconductors with a metal (aluminum) are most common
- Smaller temperature ranges (usually –55 °C to about 150°C.
- Some materials - up to 225°C
- Newer devices - up to about 800°C

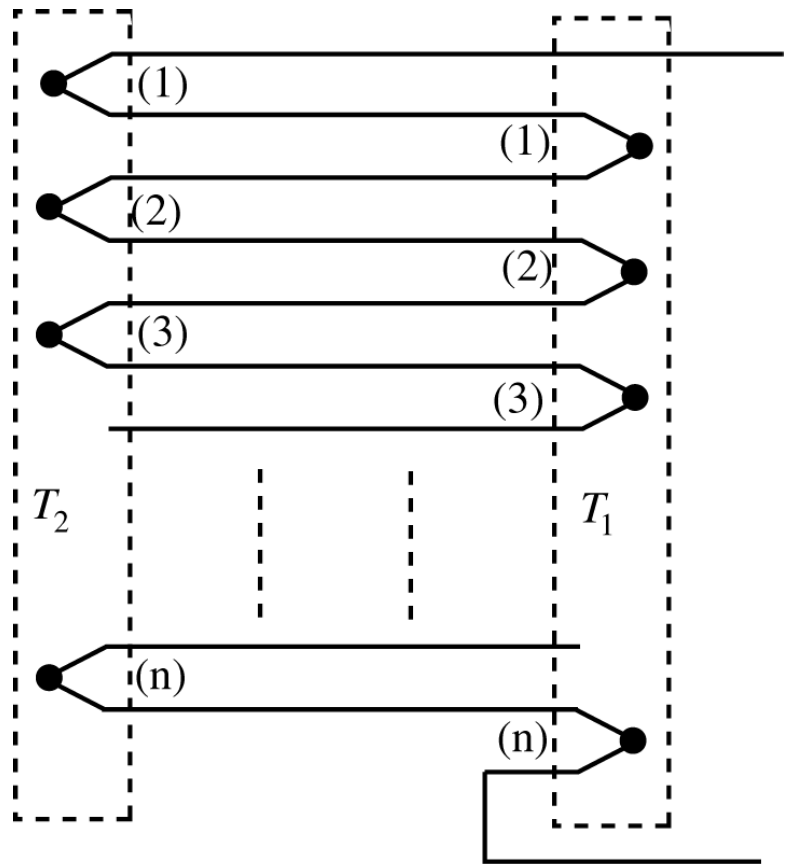
Semiconductor thermocouples: operation

- Pure semiconductor: electrons in valence/covalence bonds
- Few electrons are available for conduction
- Adding heat moves them across the energy gap into the conduction band
- To increase number of electrons - need to dope the material



Thermopile

- n thermocouples in series electrically
- In parallel thermally
- Output is n times the output of a single thermocouple



Thermopiles (cont.)

- Used to increase output
- Sometimes done with metal thermocouples
- Example: pilot flame detector: 750 mV at temperature difference of about 120°C. about 100 metal thermocouples.

Semiconductor thermopiles

- Each thermocouple has higher output than metal based devices
- A few thermocouples in series can produce relatively high voltage
- Used to produce thermoelectric generators.
- Outputs upwards of 15V are available
- Known as Peltier cells

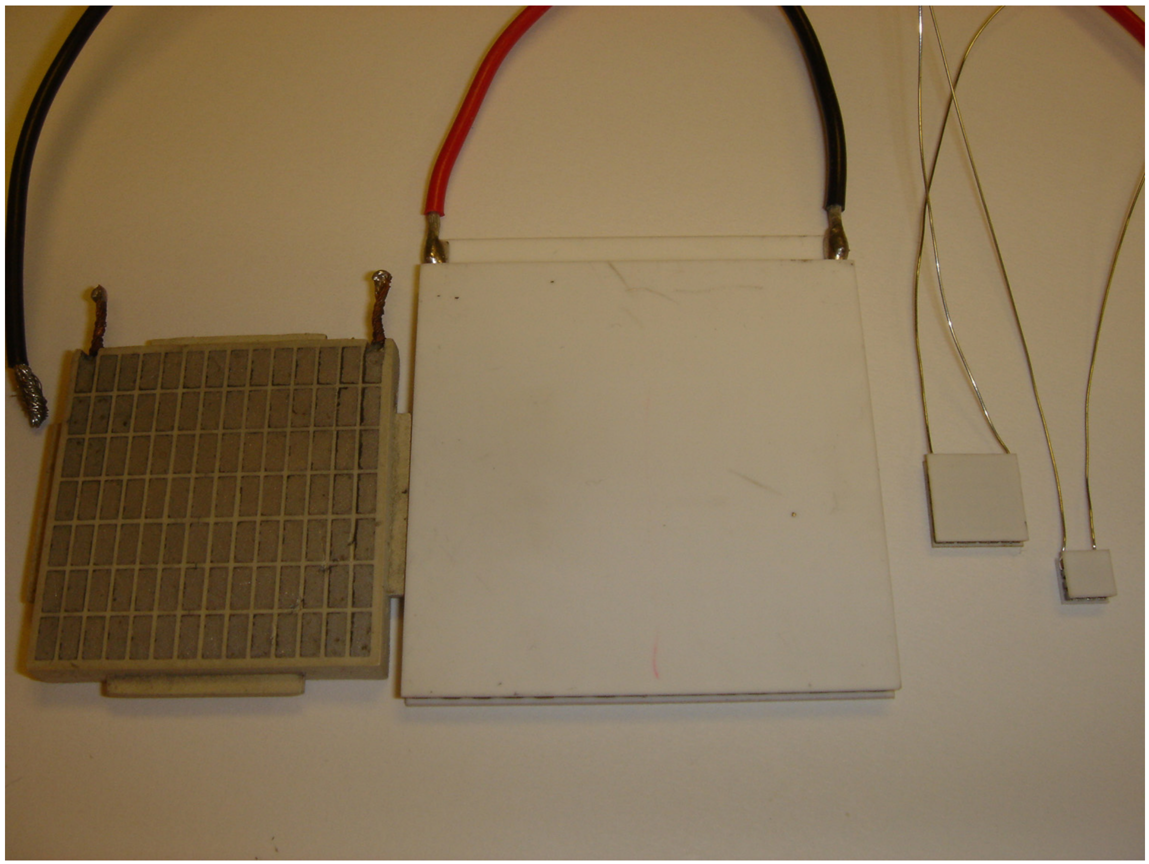
Peltier cells

- Made of crystalline semiconductor materials such as bismuth telluride (Bi_2Te_3) (n-p junctions)
- Peltier Cells are often used for cooling and heating in dual purpose refrigerators,
- Can also be used as sensors and can have output voltages of a few volts (any voltage can be achieved)
- Also used as power generators for small remote installations

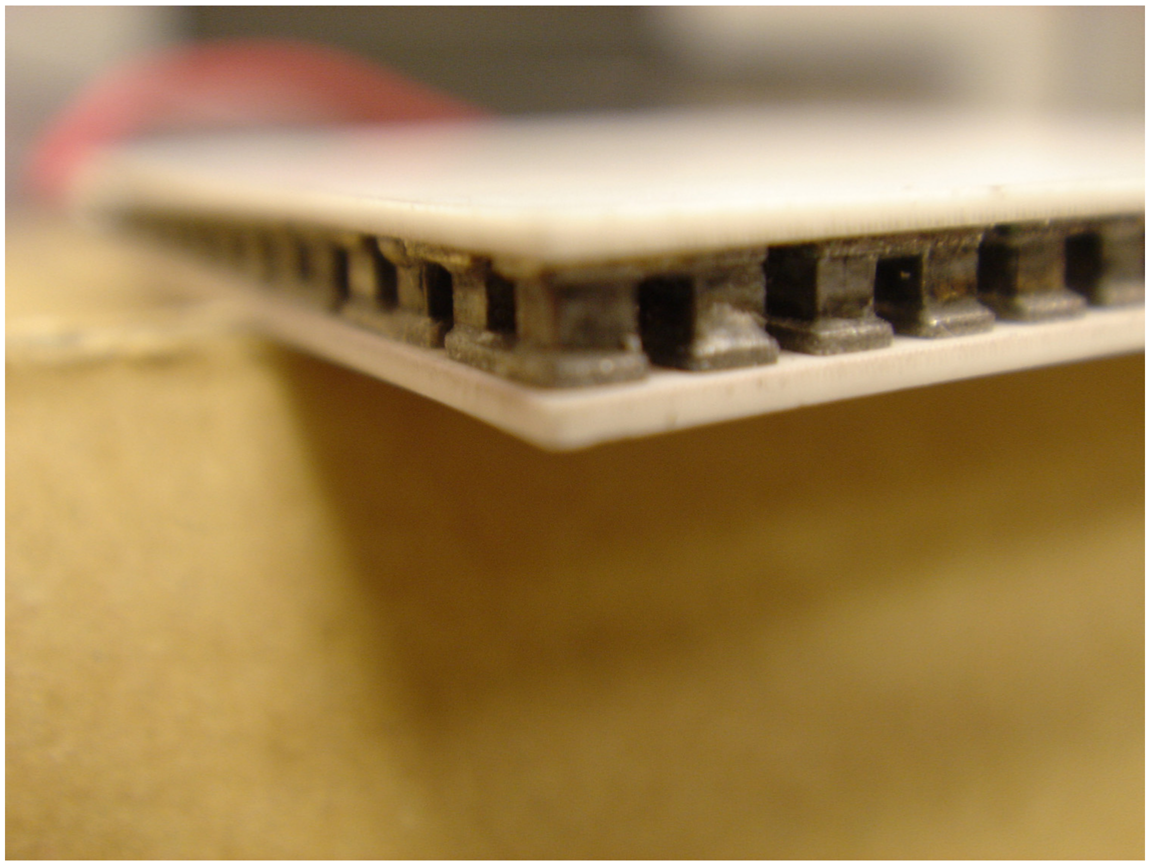
Peltier cells (cont.)

- Junctions are sandwiched between two ceramic plates
- Standard sizes are 15, 31, 63, 127 and 255 junctions
- May be connected in series or parallel, electrically and/or thermally.
- Maximum temperature difference of about 100°C
- Maximum operating temperatures of about 225°C
- Also used as power generators for small remote installations

Some thermopiles (Peltier TEGs)



Details of the TEG construction

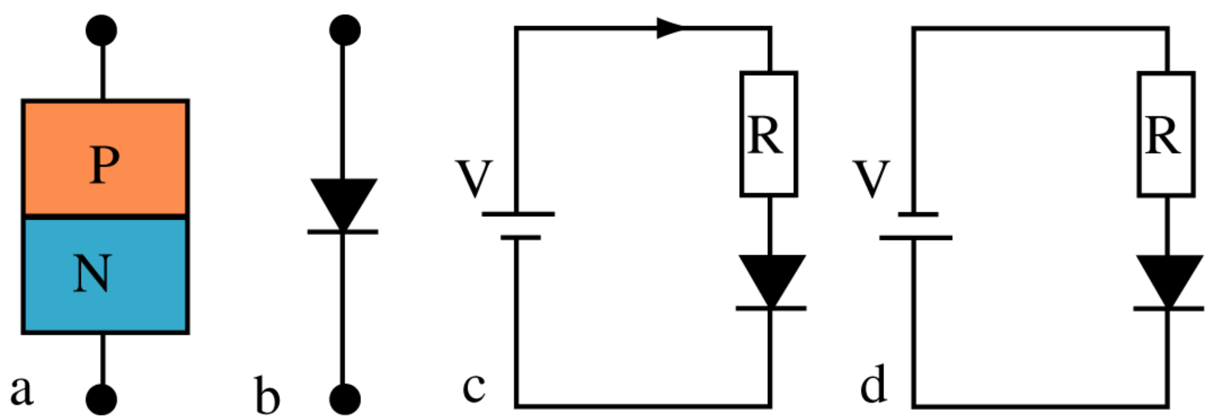


P-N Junction temperature sensors

- A junction between a p and an n-doped semiconductor
- Usually silicon (also germanium, galium-arsenide, etc.)
- This is a simple diode
- Forward biased

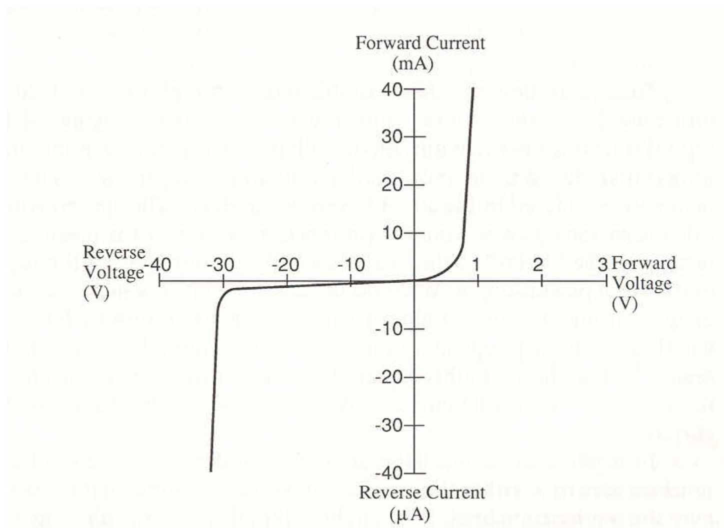
P-N junction sensor (cont.)

- Construction of the sensor



P-N junction sensor (cont.)

- Forward current is temperature dependent
- Any semiconductor diode will work
- Usually the voltage across the diode is sensed



P-N junction sensor (cont.)

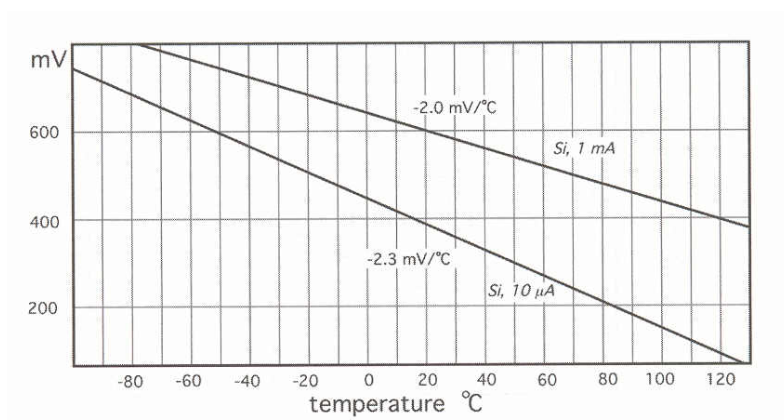
- Forward current through diode
- Voltage across diode
  - I_0 - saturation current
  - E_g - band gap energy
  - q - charge of electron
  - k - Boltzman's constant
  - C - a temp. independent constant
  - T - temperature (°K)

$$I = I_0 e^{qV/2kT}$$

$$V_f = \frac{E_g}{q} - \frac{2kT}{q} ln\left(\frac{C}{I}\right)$$

P-N junction sensor (cont.)

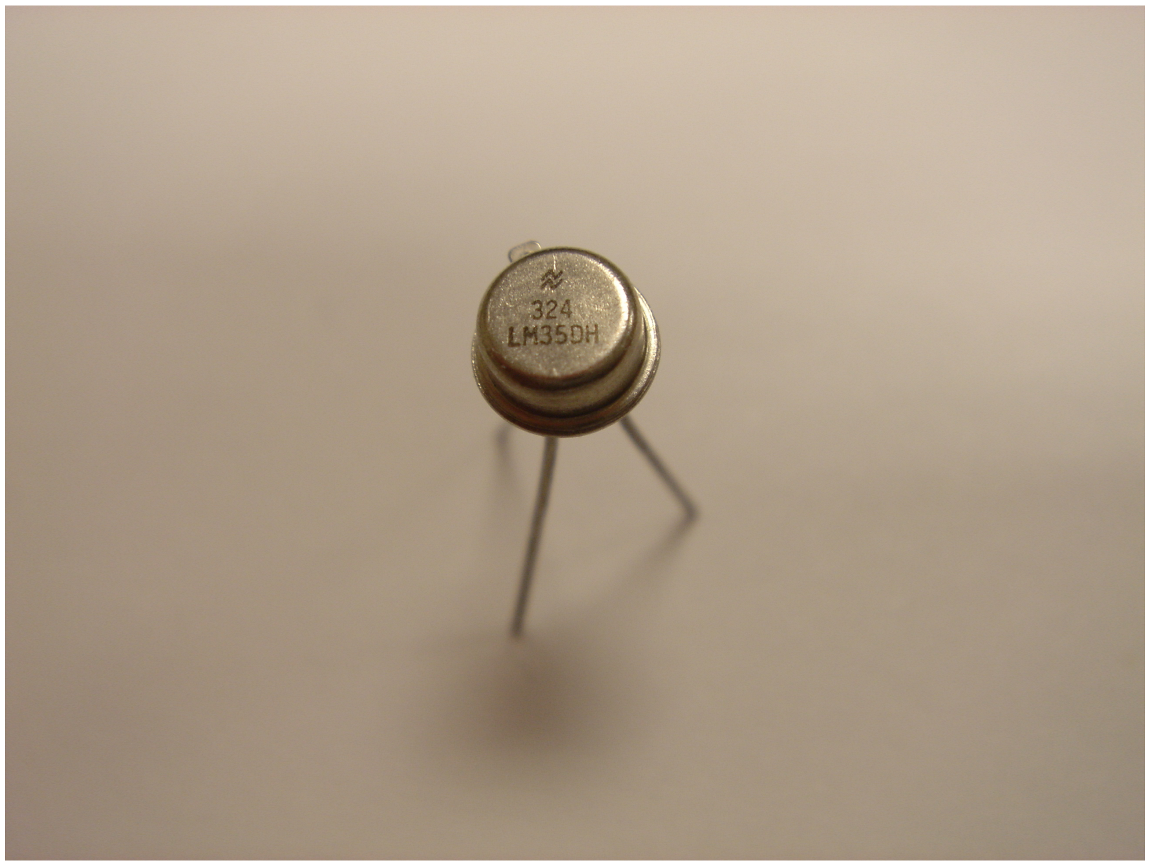
- If C and I are constant, V_f is linear with temperature
- Diode is an NTC device
- Sensitivity: 1-10mV/°C (current dependent)



P-N junction - operation parameters

- Forward biased with a current source
- 10-100μA typically (low currents - higher sensitivity)
- Maximum range (silicon) –55 to 150°C
- Accuracy: ±0.1 °C typical
- Self heating error: 0.5 mW/°C
- Packaging: as a diode or as a transistor (with additional circuitry)

The LM35 sensor



Other temperature sensors

- Optical
- Acoustical
- Thermomechanical sensors
- Thermomecahnical actuators

Optical temperature sensors

- Noncontact
- Conversion of optical radiation into heat
- Most useful in infrared temperature sensing
- Relies on quantum effects - discussed in the following chapter
- Other sensors rely on phase difference in propagation
  - Light propagates through a silicon optical fiber
  - Index of refraction is temperature sensitive
  - Phase of detected light is a measure of temperature

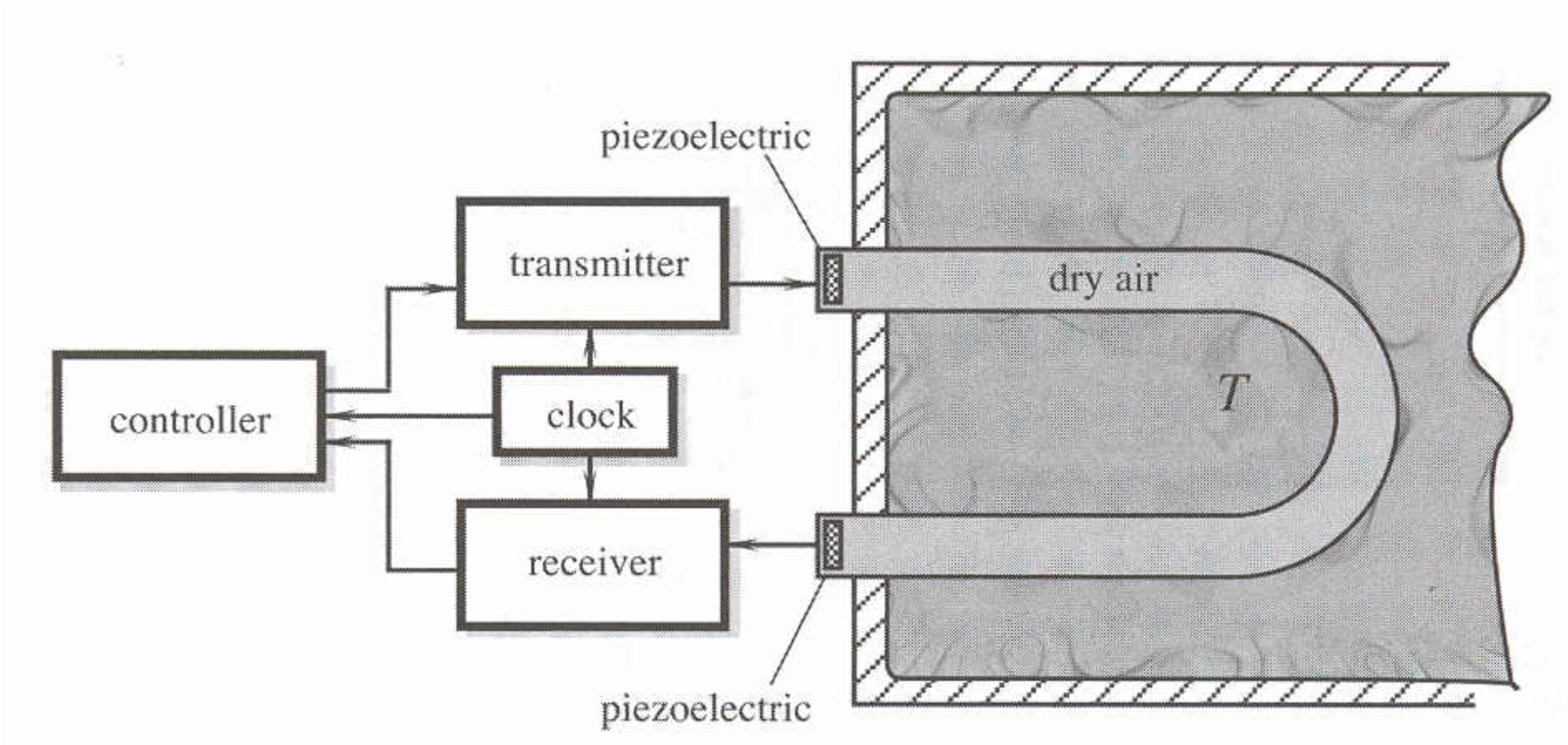
Acoustical temperature sensor

- Speed of sound is temperature dependent

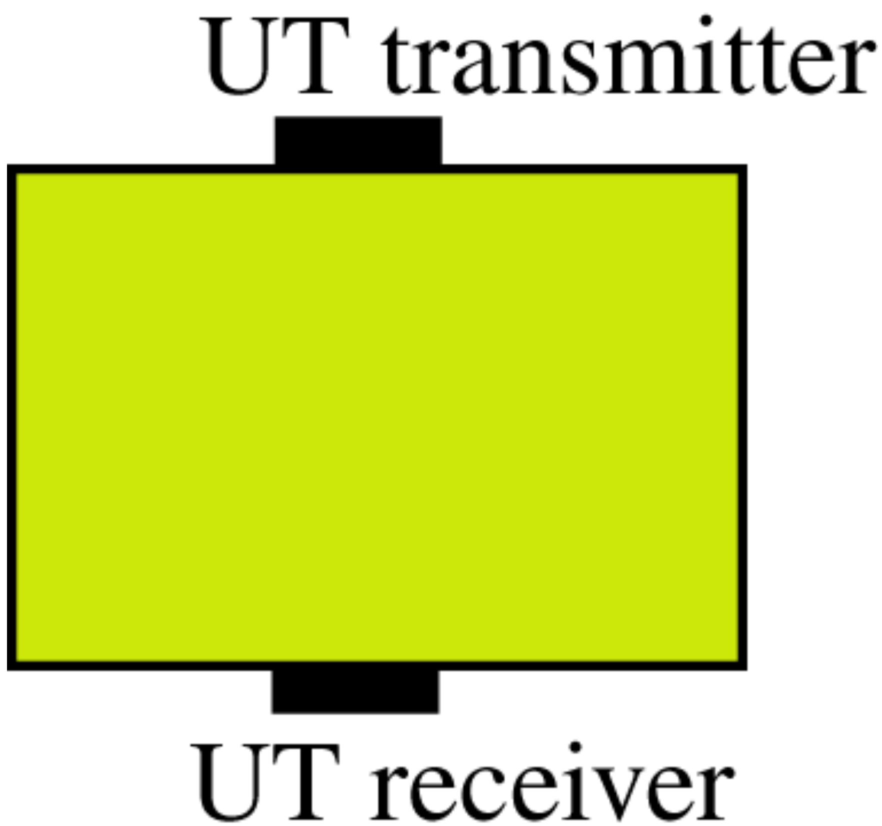
$$v_s = 331.5\sqrt{\frac{T}{273.15}} \quad \left[\frac{\text{m}}{\text{s}}\right]$$

- Measure the time it takes to travel through the heated medium
- Most sensors use ultrasonic sensors for this purpose.

Acoustical temperature sensor



Acoustical temperature sensor

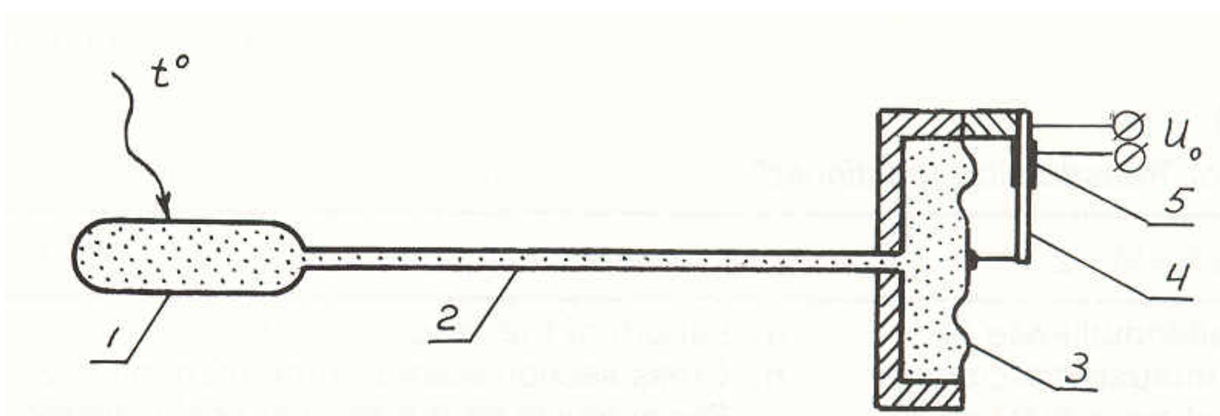


Thermo-mechanical sensors

- Changes of physical properties due to temperature
  - Length
  - Volume
  - Pressure, etc.
- Expansion of gasses and fluids (thermometers)
- Expansion of conductors (thermometers, thermostats)
- Many have a direct reading (graduation, dials)
- Some activate switches directly (thermostats)
- Examples:

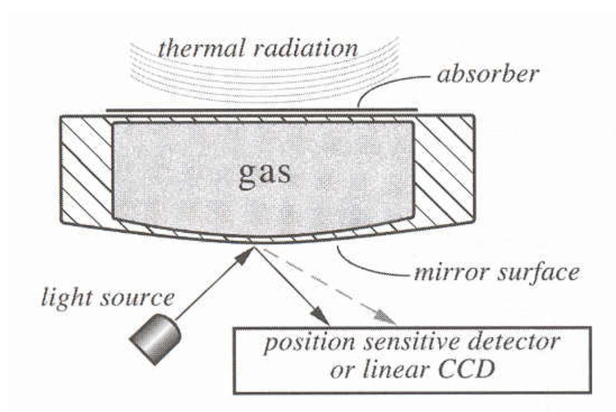
Gas expansion temperature sensor

- Rise in temperature expands the gas
- Diaphragm pushes on a "sensor" (strain gauge, potentiometer) or even a switch
- The sensor's output is graduated in temperature



Thermo-pneumatic sensor

- Called a Golay cell
- Gas expands in a flexible cell
- Motion moves a mirror and deflects light
- Extremely sensitive device



Thermal expansion of metals

- All metals expand with temperature
- Volume stays constant - length changes
- Each metal has a coefficient of linear expansion α.
- α is usually given at T_1, temperatures in °C.

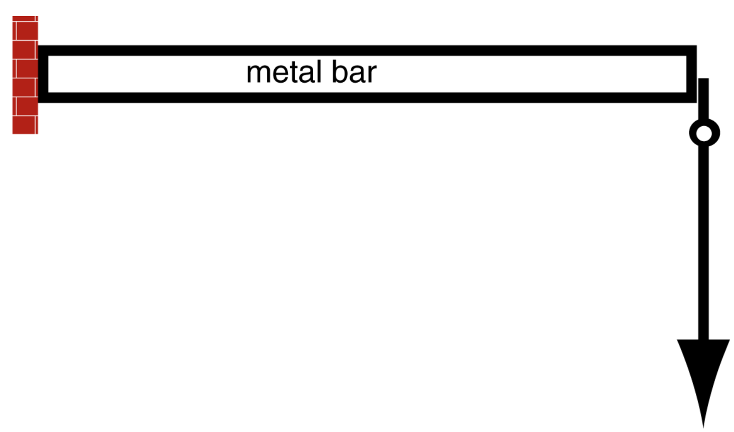
$$l_2 = l_1\left[1 + \alpha\left(T_2 - T_1\right)\right] \qquad [\mathrm{m}]$$

Thermal expansion of metals

- Coefficients of linear expansion are small
- They are however measurable
- Can be used to directly operate a lever to indicate temperature
- Can be used to rotate a shaft
- In most cases the bimetal configuration is used
- Serve as sensors and as actuators

Example: direct dial indication

- Metal bar expands as temperature increases
- Dial arrow moves to the left as temperature rises
- Very small motion
- The dial can be replaced to a pressure sensor or a strain gauge

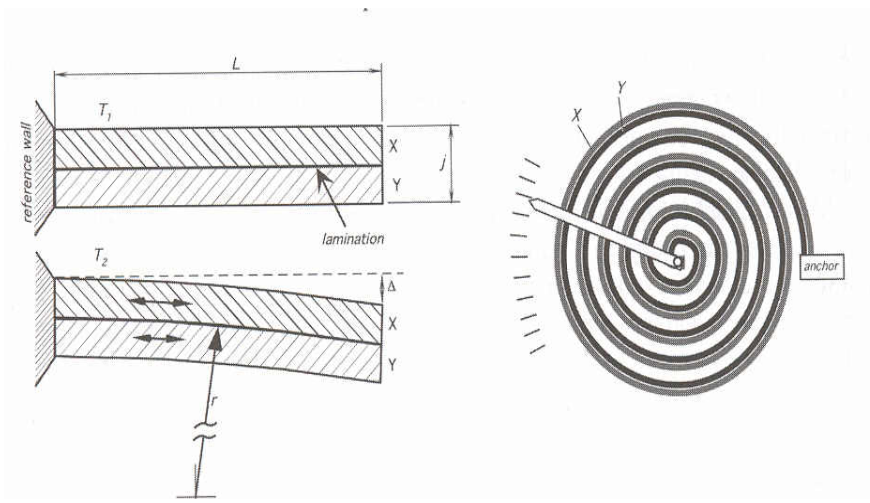


Bimetal sensors

- Two metal strips welded together
- Each metal strip has different coefficient of expansion
- As they expand, the two strips bend. This motion can then be used to:
  - move a dial
  - actuate a sensor (pressure sensor for example)
  - rotate a potentiometer
  - close a switch

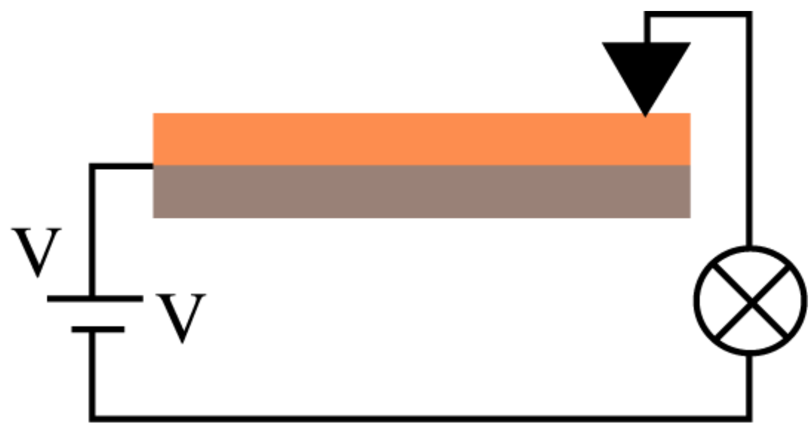
Bimetal sensors (cont.)

- To extend motion, the bimetal strip is bent into a coil. The dial rotates as the coil expands/contracts

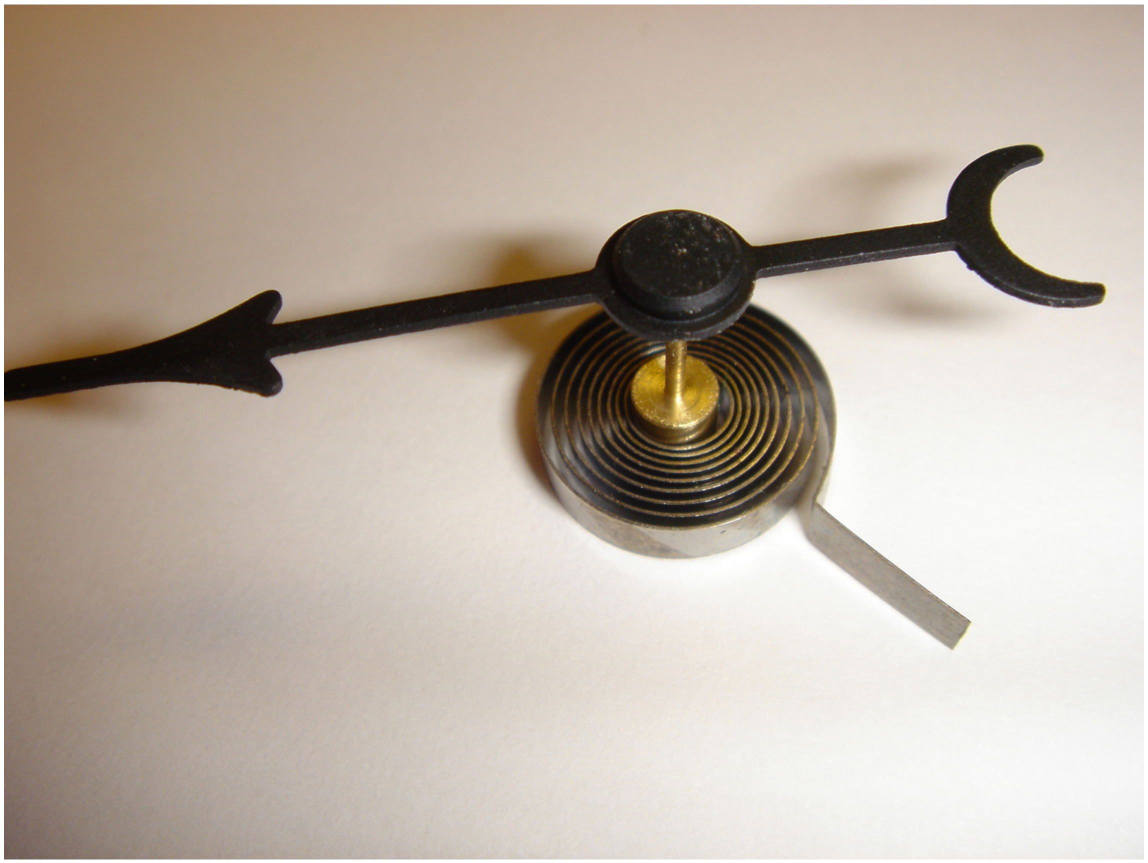


Bimetal switch (example)

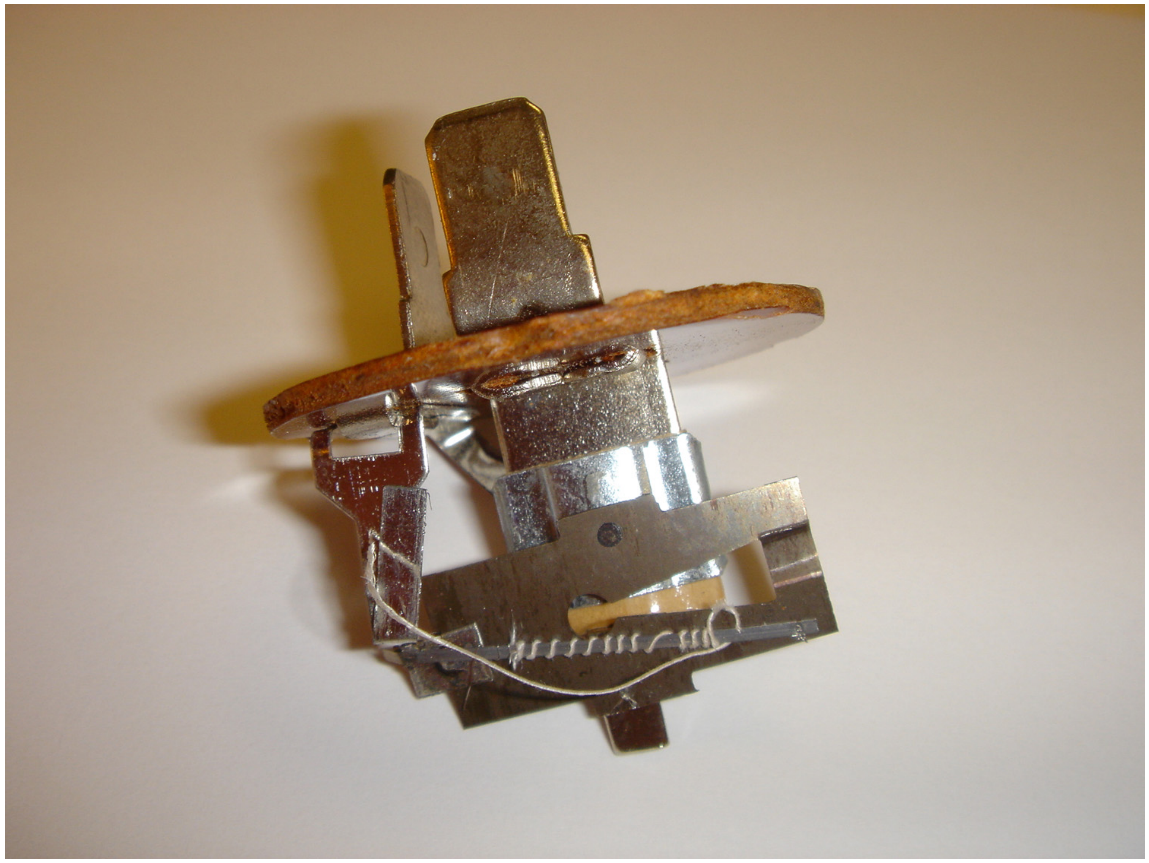
- Typical uses: flashers in cars, thermostats)
- Operation
  - Left side is fixed
  - Right side moves down when heated
  - Cooling reverses the operation



Bimetal coil thermometer



Bimetal switch (car flasher)

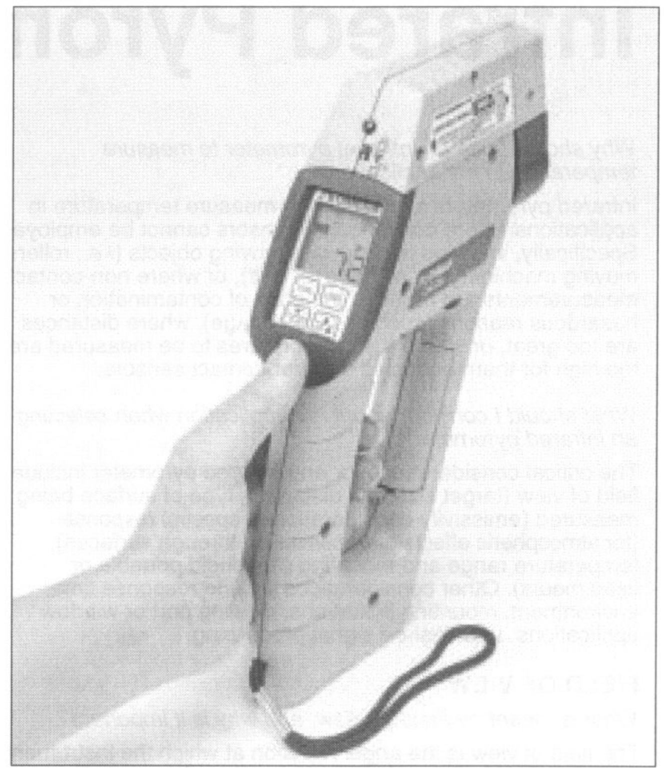


Infrared Thermometry

- Infrared thermometers measure the amount of radiation emitted by an object.
- Peak magnitude is often in the infrared region.
- Surface emissivity must be known. This can add a lot of error.
- Reflection from other objects can introduce error as well.
- Surface whose temp you' re measuring must fill the field of view of your camera.

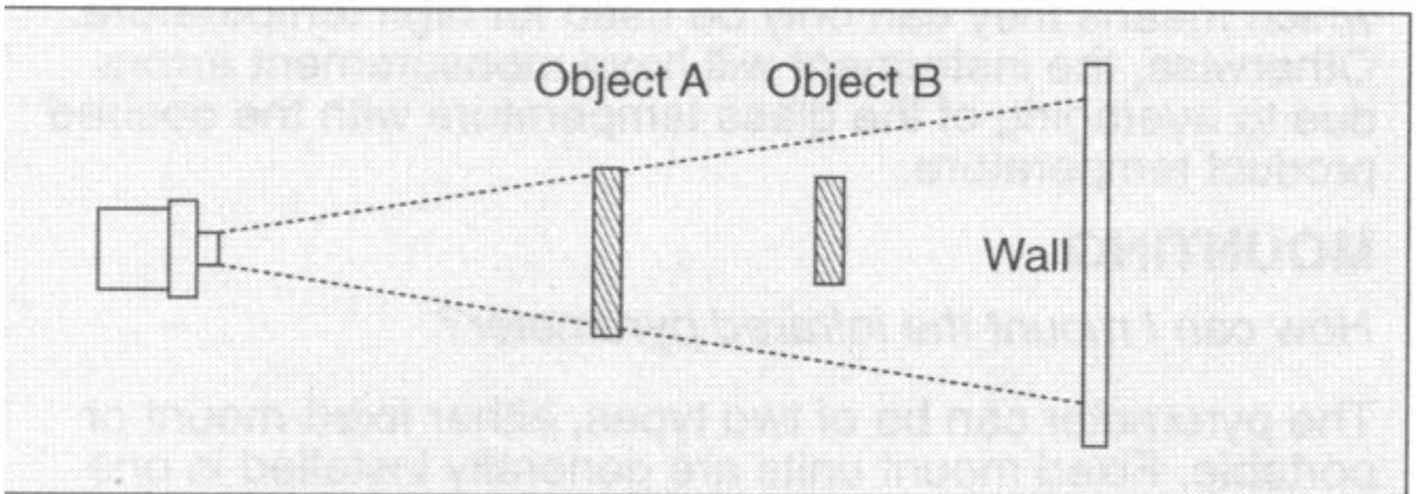
Benefits of Infrared Thermometry

- Can be used for
  - Moving objects
  - Non-contact applications where sensors would affect results or be difficult to insert or conditions are hazardous
  - Large distances
  - Very high temperatures



Field of View

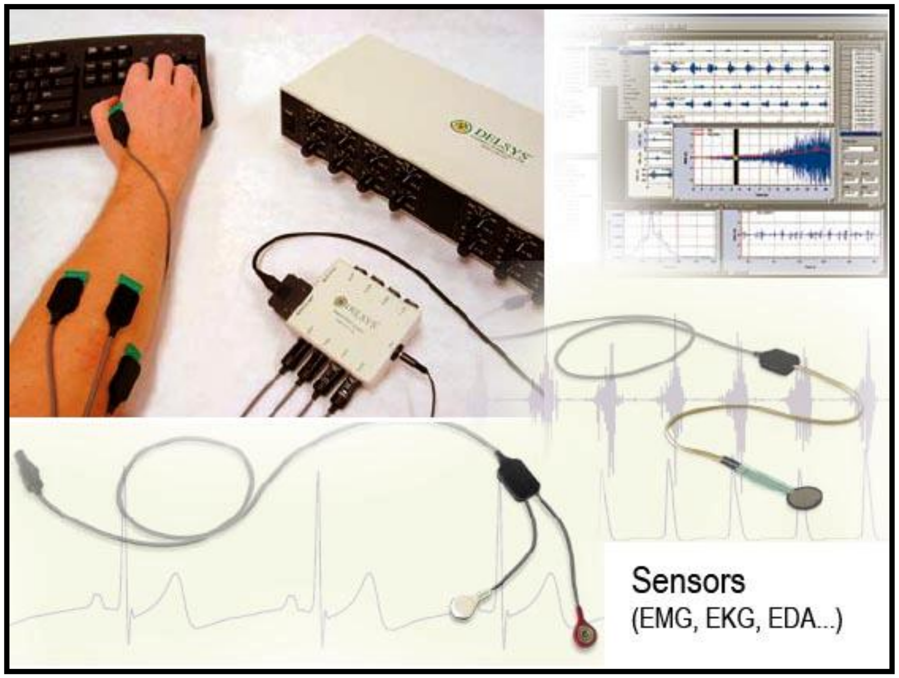
- On some infrared thermometers, FOV is adjustable.



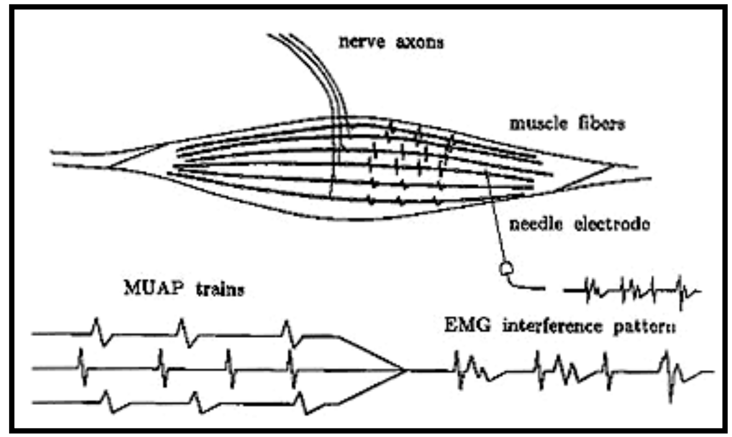
Electromyogram (EMG)

- Electromyogram (EMG) is a technique for evaluating and recording the activation signal of muscles.
- EMG is performed by an **electromyograph**, which records an **electromyogram**.
- Electromyograph detects the electrical potential generated by muscle cells when these cells contract and relax.

Electromyogram (EMG)



EMG Apparatus



Muscle Structure/EMG

Electromyogram (EMG)

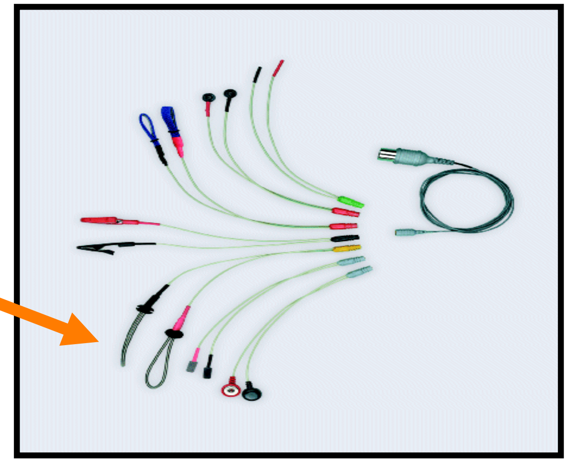
- The electrical source is the muscle membrane potential of about -70mV.
- Measured EMG potentials range between

  < 50 µV up to 20 to 30 mV, depending on the muscle under observation.
- Typical repetition rate of muscle unit firing is about 7−20 Hz.
- Damage to motor units can be expected at ranges between 450 and 780 mV

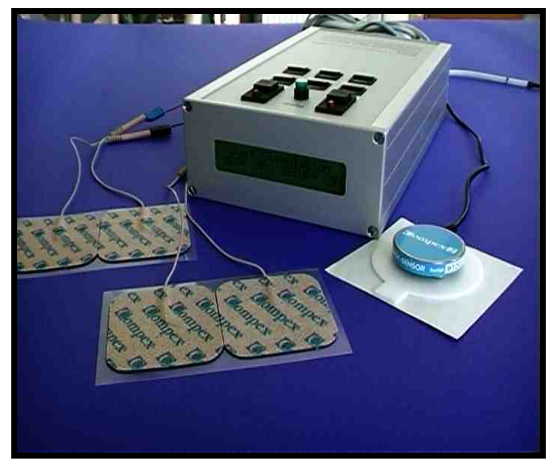
Electromyogram (EMG)

Intramuscular -

Needle Electrodes

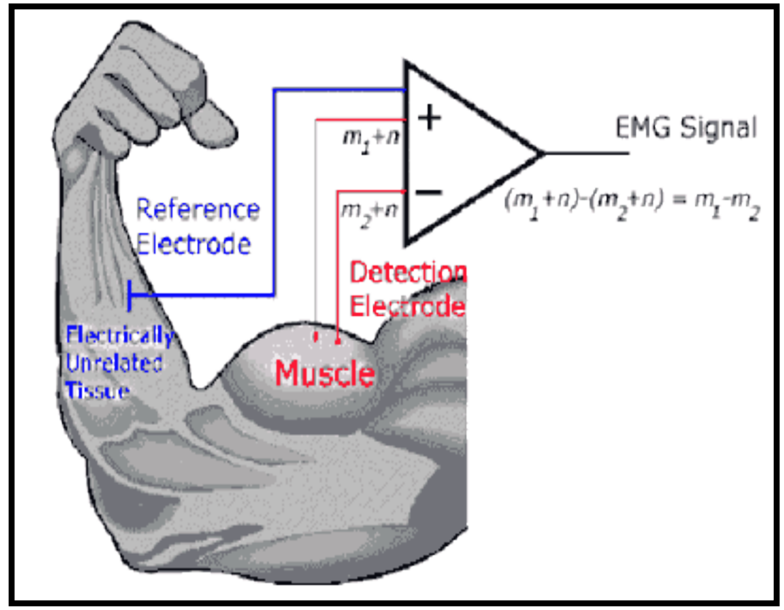


Extramuscular - Surface Electrodes



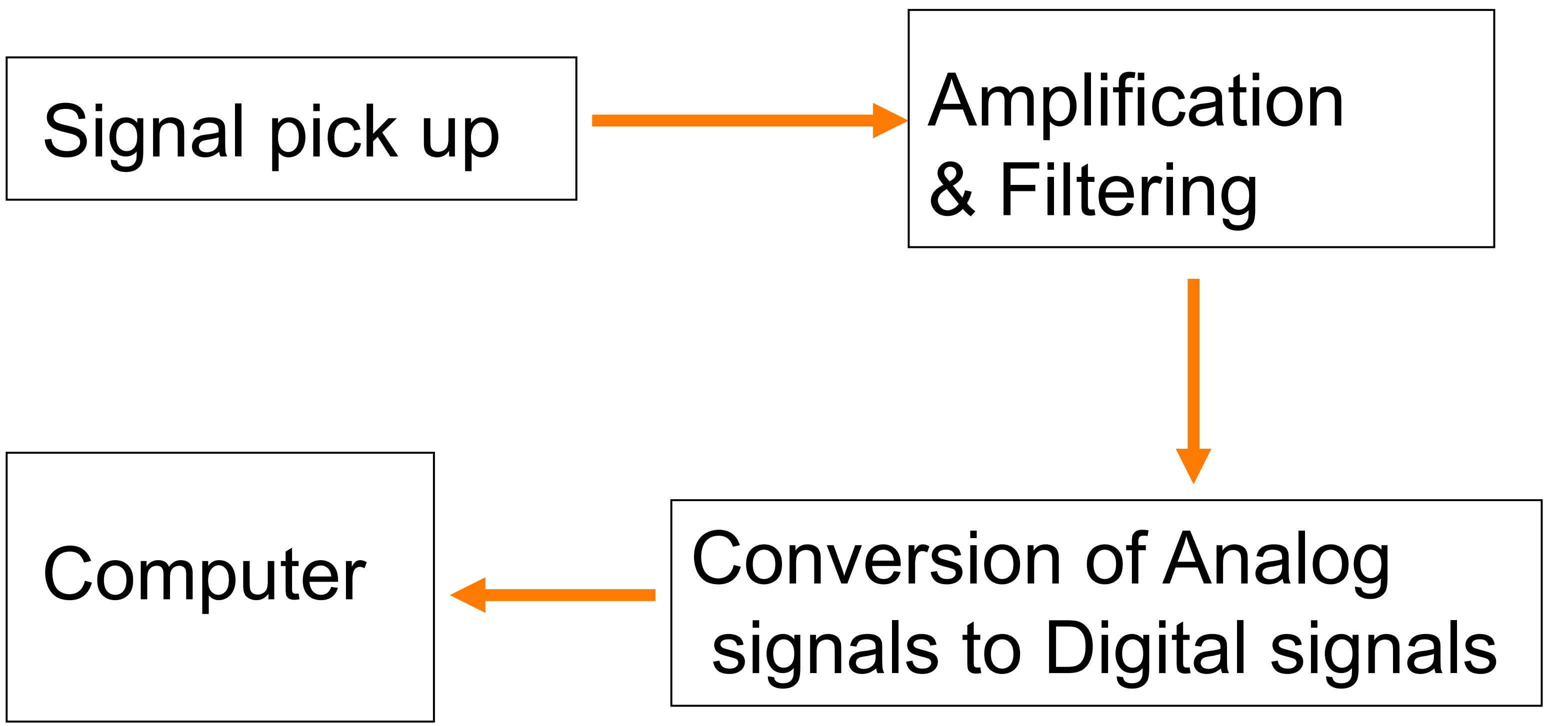
Electromyogram (EMG)

- Clean the site of application of electrode;
- Insert needle/place surface electrodes at muscle belly;
- Record muscle activity at rest;
- Record muscle activity upon voluntary contraction of the muscle.



Electromyogram (EMG)

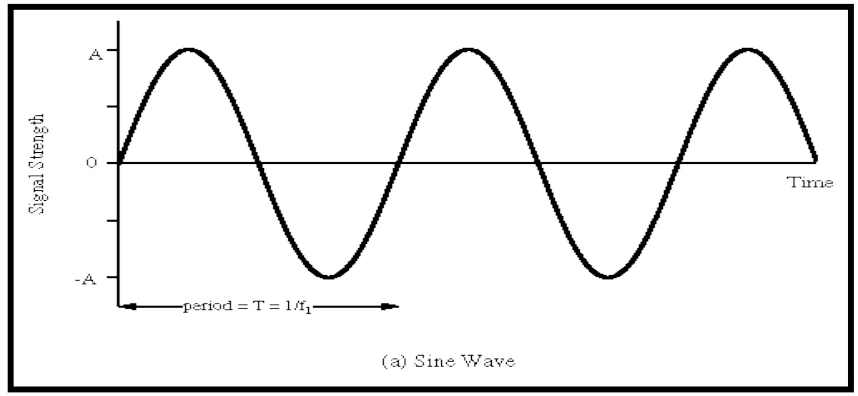
EMG processing:



Electromyogram (EMG)

- Muscle Signals are Analog in nature.

- EMG signals are also collected over a specific period of time.



Analog Signal