Temperature Measurement

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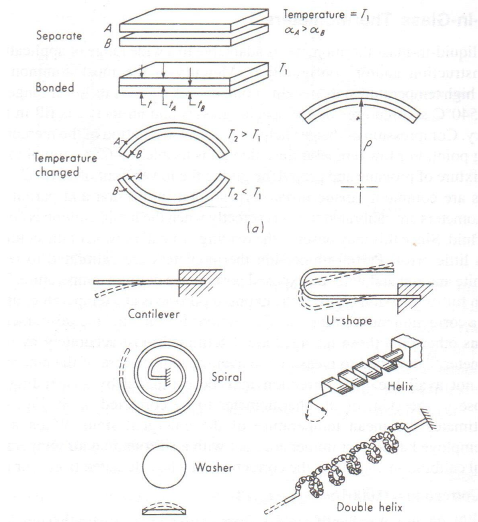
Bimetallic Thermometer

- If two strips of metals A and B with different thermal-expansion coefficent α_A and α_B are firmly bonded together, a temperature change causes differential expansion and the strip to deflect its unrestrained end
- The resulting radius of curvature:

$$\rho = \frac{t\{3(1+m)^2 + (1+mn)[m^2 + 1/(mn)]\}}{6(\alpha_A - \alpha_B)(T_2 - T_1)(1+m)^2}$$

ρ: radius of curvature; t: total strip thickness, n: elastic modulus ratio (E_B/E_A), m: thickness ratio (t_B/t_A), (T_2-T_1): temperature rise

Bimetallic Thermometer (contd)



Bimetallic Thermometer (contd)

- Utilized in temperature measurements
- Used in sensing and control elements in temperature control systems (mostly on-off type)
- Used in overload cut-off switches (cut-off when excessive current flow through it)
- Employ mechanical motion to generate opposing compensation effect
- Combine with potentiometer for automotive sensing applications

- Low-cost unless requirement is very critical
- Working range: -70 to 540 ^oC
- Inaccuracy: 0.5-1% of full scale of high quality

Liquid-in-Glass Thermometers

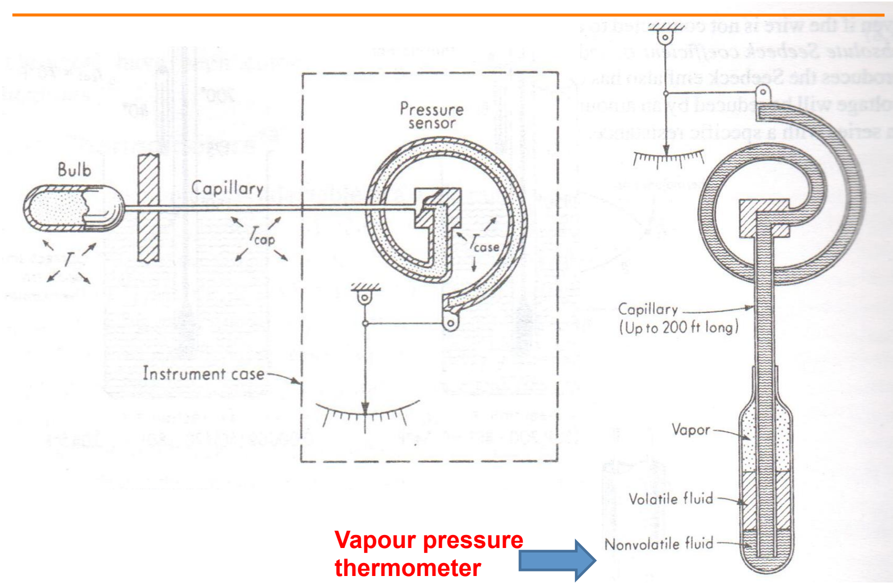
- Hg is the most commonly used liquid. Limited by its freezing point (of -39 ^{o}C)
- For low temperature requirement: use alcohol (-62 ^{o}C), toluol (-90 ^{o}C), pentane (-200 ^{o}C), propane/ propylene mixture (-218 ^{o}C)

- Two types: Total immersion & partial immersion
- Problem in noting the reading with total immersion
- Partial immersion reads correctly when immersed by the right amount and ambient at definite temperature
- Corrections needs otherwise
- Accuracy can be as high as 0.04 ^{o}C with total immersion thermometers

Pressure Thermometers

- Consists of a sensitive bulb, interconnecting capillary tube, pressure-measuring device (such as Bourdon tube)
- Liquid-filled systems cover -100 to 400 ^{o}C with xylene, -39 to 590 ^{o}C with Hg
- Gas-filled systems cover -240 to 650 ^{o}C
- Vapor-filled (ethane, ethyl chloride, chlorobenzene) systems cover -40 to 316 ^{o}C
- Best accuracy: +/-0.5% of the full scale

Pressure Thermometers



Vapour pressure thermometer

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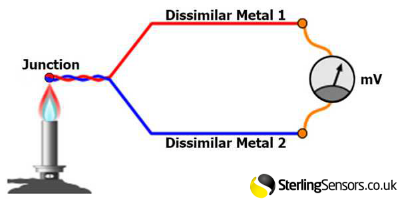
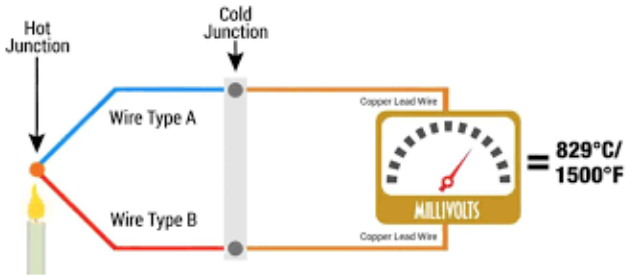
Thermocouples



- If two wires of different materials A and B are connected in the circuit, with two junctions at different temperatures, then an electromotive force is generated between the junctions
- The magnitude of E generated depends on the two materials and the temperatures
- Common material pairs are:
  - Chromel ($Ni_{90}Cr_{10}$) – Constantan ($Cu_{57}Ni_{43}$) (Type E)
  - Iron – Constantan (Type J)
  - Copper – Constantan (Type T)
  - Chromel ($Ni_{90}Cr_{10}$) – Alumel ($Ni_{94}Mn_3Al_2Si_1$) (Type K)
  - Platinum 13% rhodium – Platinum (Type R)
  - Platinum 10% rhodium – Platinum (Type S)
  - Nirosil – Nisil (Type N)



Thermocouple (contd)

Iron – Constantan (Type J): Range -150 to 1000 ^{o}C. Most commonly used for industrial applications.

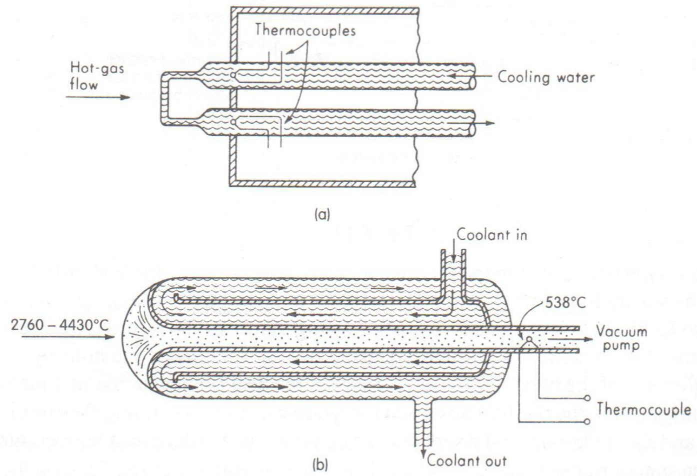
Copper – Constantan (Type T): Range -200 to 350 ^{o}C. Oxidation of copper above 350 ^{o}C

Chromel – Alumel (Type K): Range -200 to 1300 ^{o}C. Linear temperature-voltage characteristics

Platinum rhodium/Platinum (Types R/S): Range 0 to 1500 ^{o}C. Attractive because of chemical inertness and stability at high temperatures in oxidizing atmosphere

Nirosil – Nisil (Type N): Developed to overcome problems with K-types thermocouples

Special Thermocouples



Cooled thermocouples for measurement in hot-gas flow

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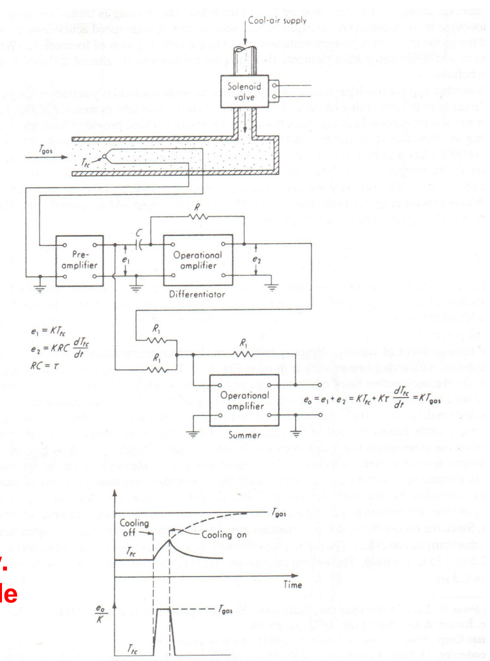
Special Thermocouples



Pulsed thermocouples for measurement in hot-gas flow. Here, cooling of thermocouple cut-off for some time

Electrical-Resistance Sensors

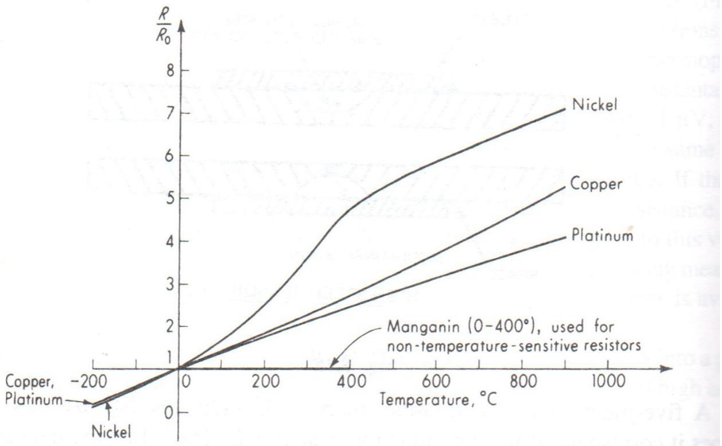
- Electrical resistance of various materials changes in a reproducible manner with temperature, thus forming the basis of a temperature-sensing method
- Materials can be conducting or semi-conductors
- Sensor with conducting material called *resistance temperature detector* (RTD)
- Sensor with semi-conducting material called *thermistor*

Resistance Temperature Detector

- Equation used for variation of R with T
  $R = R_o(1 + a_1T + a_2T^2 + \ldots + a_nT^n)$ (Note R = R_o at T = 0)
- Number of terms required depends on material, desired accuracy, and temperature range
- Platinum, nickel and copper are mostly commonly used. They require 2, 3, 3 constants
- Tungsten and nickel alloys are also used
- Bridge circuit (e.g. Wheatstone) employed to sense change in resistance

Resistance Temperature Curve

$$R = R_0(1 + a_1 T + a_2 T^2 + \cdots + a_n T^n)$$



Thermistors

- Unlike RTD, they are highly non-linear.
- They have large negative resistance-temperature coefficient

  $$R = R_o e^{\beta(1/T - 1/T_o)}$$

- Silicon doped with boron, can yield positive or negative temperature coefficient depending on temperature range
- Germanium doped with arsenic, gallium, or antimony is employed for cryogenic temperatures (T < 123 K)
- Available in form of beads, flakes, rods, and disks

Thermistor R-T curve