Instrumentation-Sensors (what)

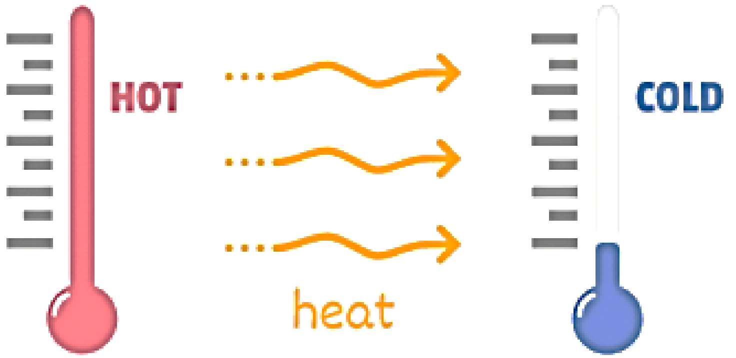
- Introduction: principles and fundamentals of Process Measurement and Instrumentation
- Pressure Measurement
- Flow Measurement
- Level Measurement
- **Temperature Measurement**
- Sensors

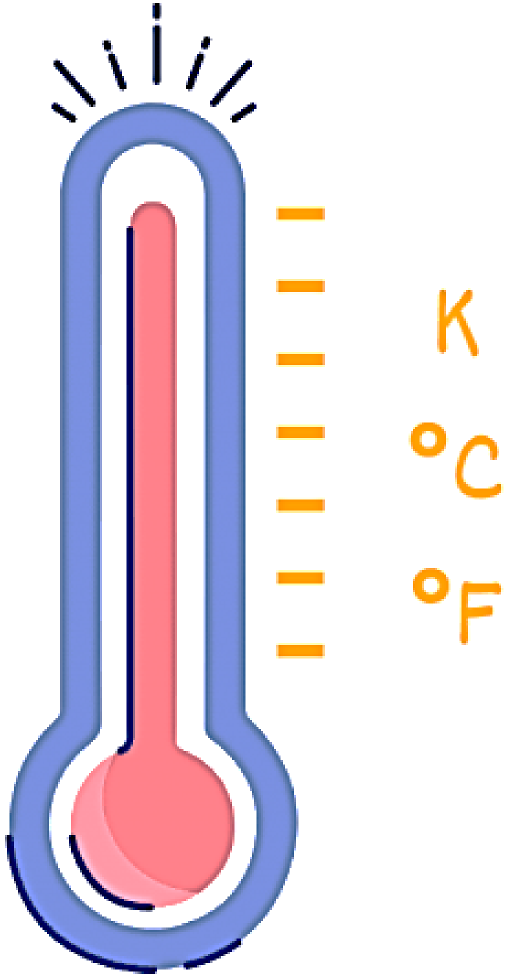
TEMPERATURE MEASUREMENT

What Is Temperature?

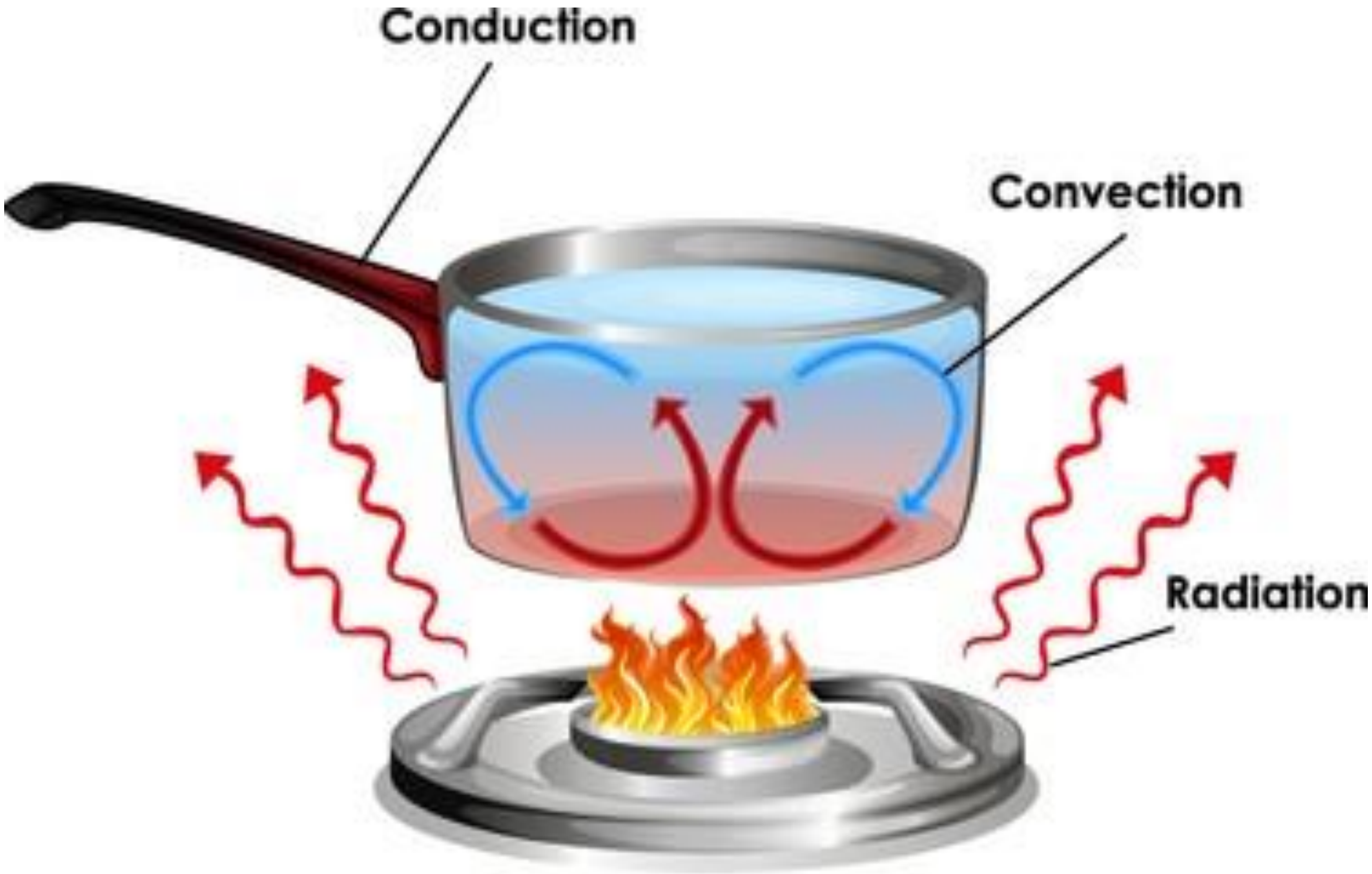
Temperature is a measure of the hotness or coldness of matter.

- Temperature indicates the average kinetic energy of particles.
- It is measured using a thermometer.
- Heat is the energy flow between two objects at different temperatures.
- There is no heat flow between two objects at the same temperature.

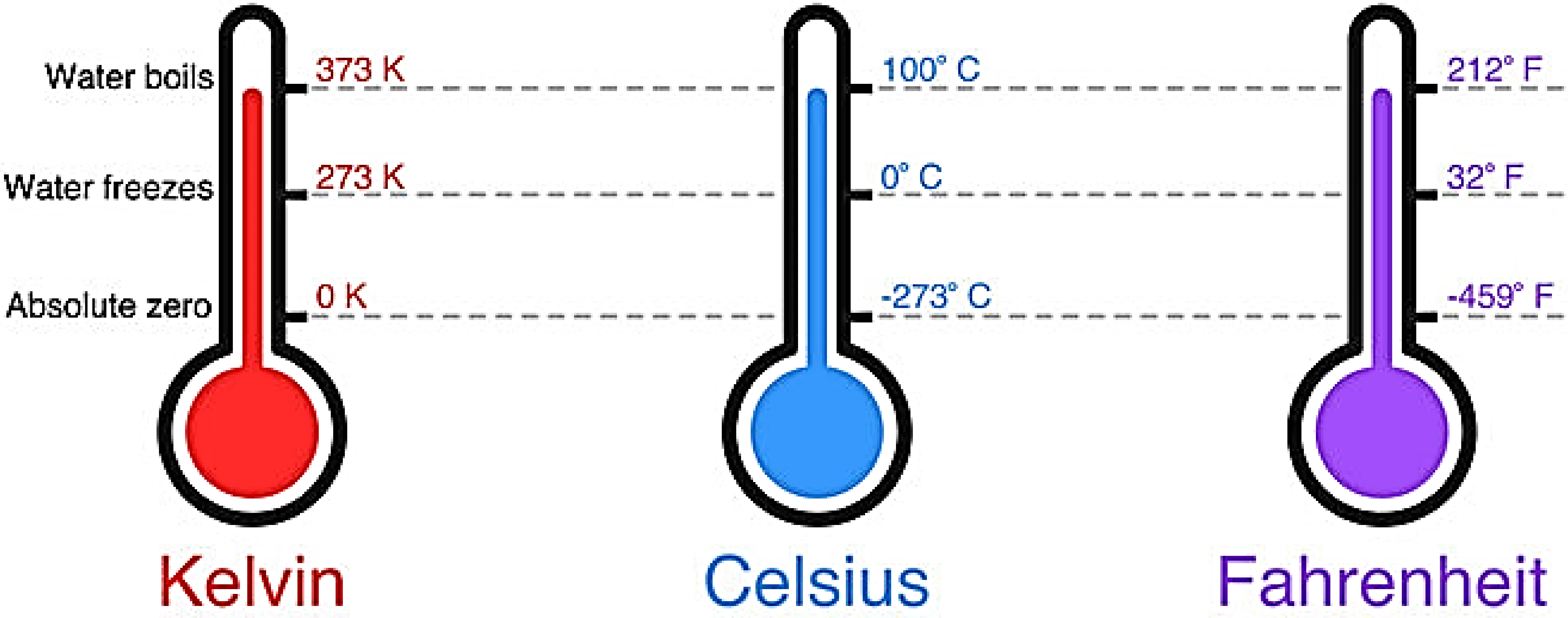




Types of Heat Transfer



Temperature Scales



Temperature Conversions

To convert	Use this equation:	Use this equation:
Celsius to Fahrenheit $^0C \rightarrow {}^0F$	$^0F = \left(\frac{9}{5} \times {}^0C\right) + 32$	Convert 45 °C to °F. $^0F = \left(\frac{9}{5} \times 45\,{}^0C\right) + 32 = 113\,{}^0F$
Fahrenheit to Celsius $^0F \rightarrow {}^0C$	$^0C = \frac{5}{9} \times \left({}^0F - 32\right)$	Convert 68 °F to °C. $^0C = \frac{5}{9} \times \left(68\,{}^0F - 32\right) = 20\,{}^0C$
Celsius to Kelvin $^0C \rightarrow K$	$K = {}^0C + 273$	Convert 45 °C to K. $K = 45\,{}^0C + 273 = 318\,K$
Kelvin to Celsius $K \rightarrow {}^0C$	$^0C = K - 273$	Convert 32 to °C. $^0C = 32\,K - 273 = -241\,{}^0C$

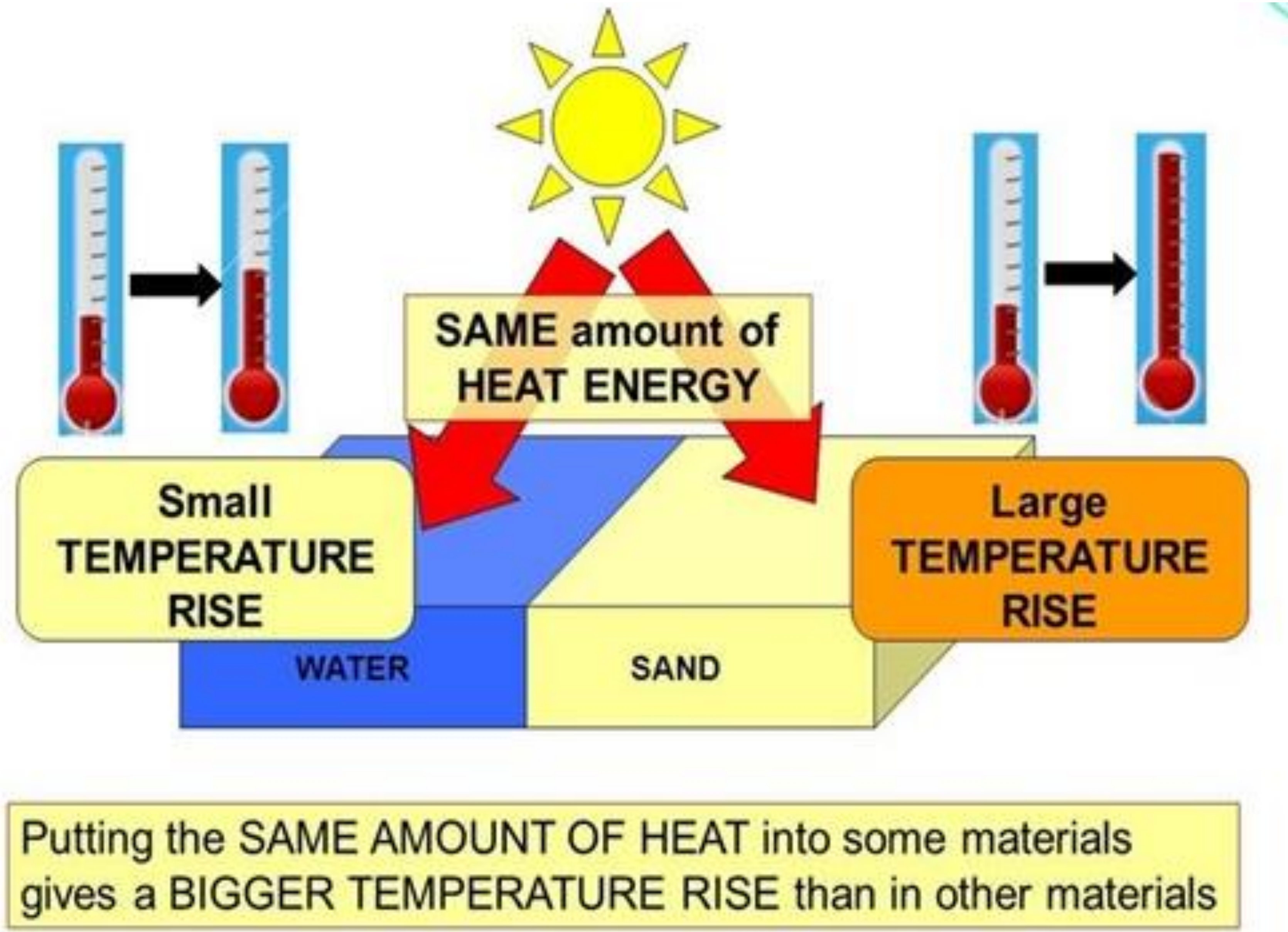
Heat capacity vs Specific heat capacity

Heat capacity	Specific heat capacity
Heat capacity (C) is defined as the amount of heat absorbed (Q) in order to increase the temperature (ΔT) by 1 unit.	**Specific heat capacity (c)** is defined as the amount of heat absorbed (Q) in order to increase the temperature (ΔT) by 1 unit, of a unit mass(m).
Heat capacity is the ratio of heat supplied (Q) to the body to the change in it's temperature ΔT.	**Specific heat capacity** is the ratio of heat capacity (C) of the body to the unit mass (m) of that body.
The formula for heat capacity is given by; **$C = Q/\Delta T$**	The formula for specific heat capacity is given by; **$c = Q/m\Delta T$**
The unit of heat capacity is **J/K**.	The unit of specific heat capacity is **J/kg K**.

Specific heat capacity of common substances

Substance	Specific Heat Capacity, C (J/g·°C)
Water (liquid)	4.184
Ice at 0°C	2.010
Steam at 100°C	1.996
Aluminum	0.902
Chromium	0.461
Lead	0.128
Magnesium	1.020
Mercury	0.140
Tin	0.213
Zinc	0.387

Heat capacity vs Specific heat capacity



Temperature Measuring Devices

Instruments to measure temperature can be divided into separate classes according to the physical principle on which they operate. The main principles used are,

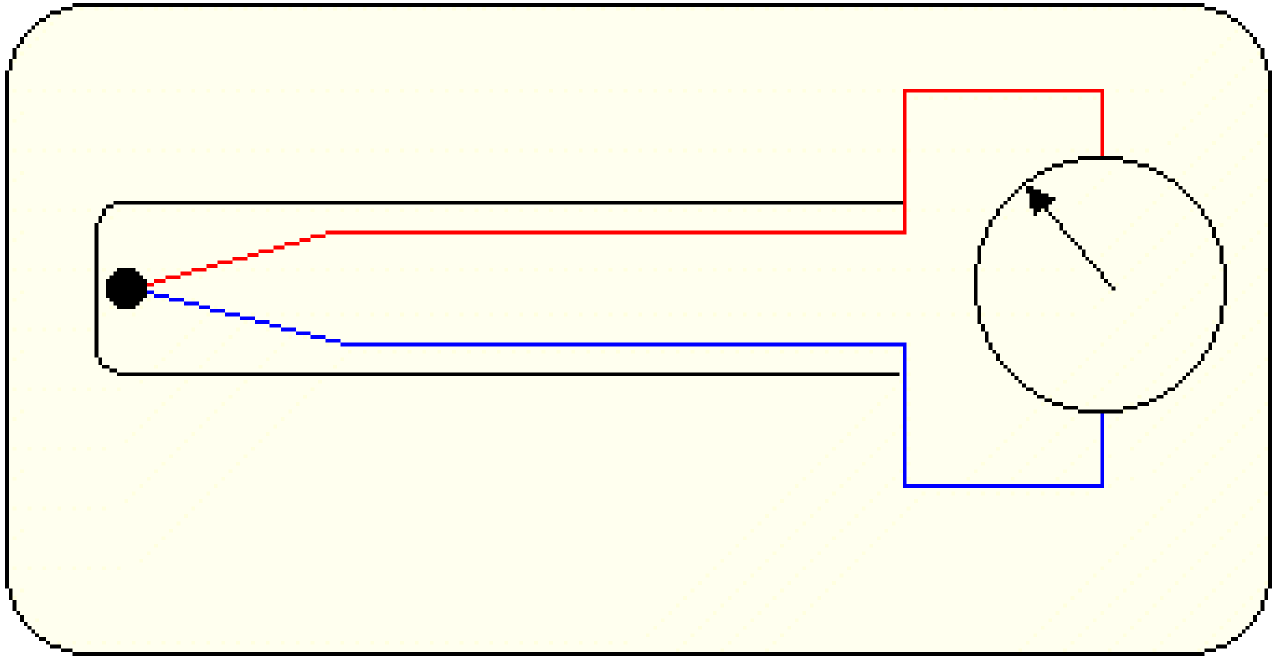
- Thermoelectric Effect
- Thermal Expansion
- Resistance Change
- Radiative Heat Emission
- Thermography
- Colour Change
- Sensitivity of Semiconductor Device
- Resonant Frequency Change
- Sensitivity of Fiber Optic Devices

Thermoelectric Effect

Thermoelectric Effect

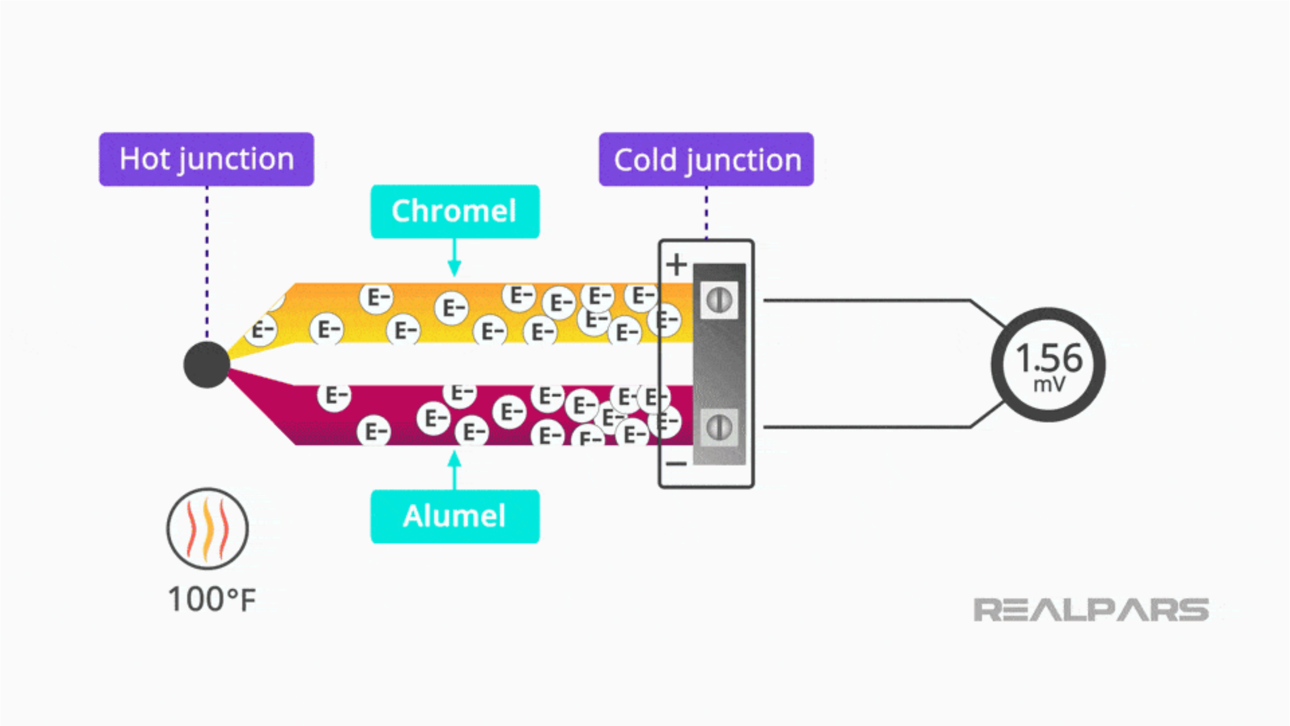
Thermocouples

J. Seebeck (1821) discovered that when any two different metals are connected together, an e.m.f., is generated at the junction between the metals.



Thermocouple

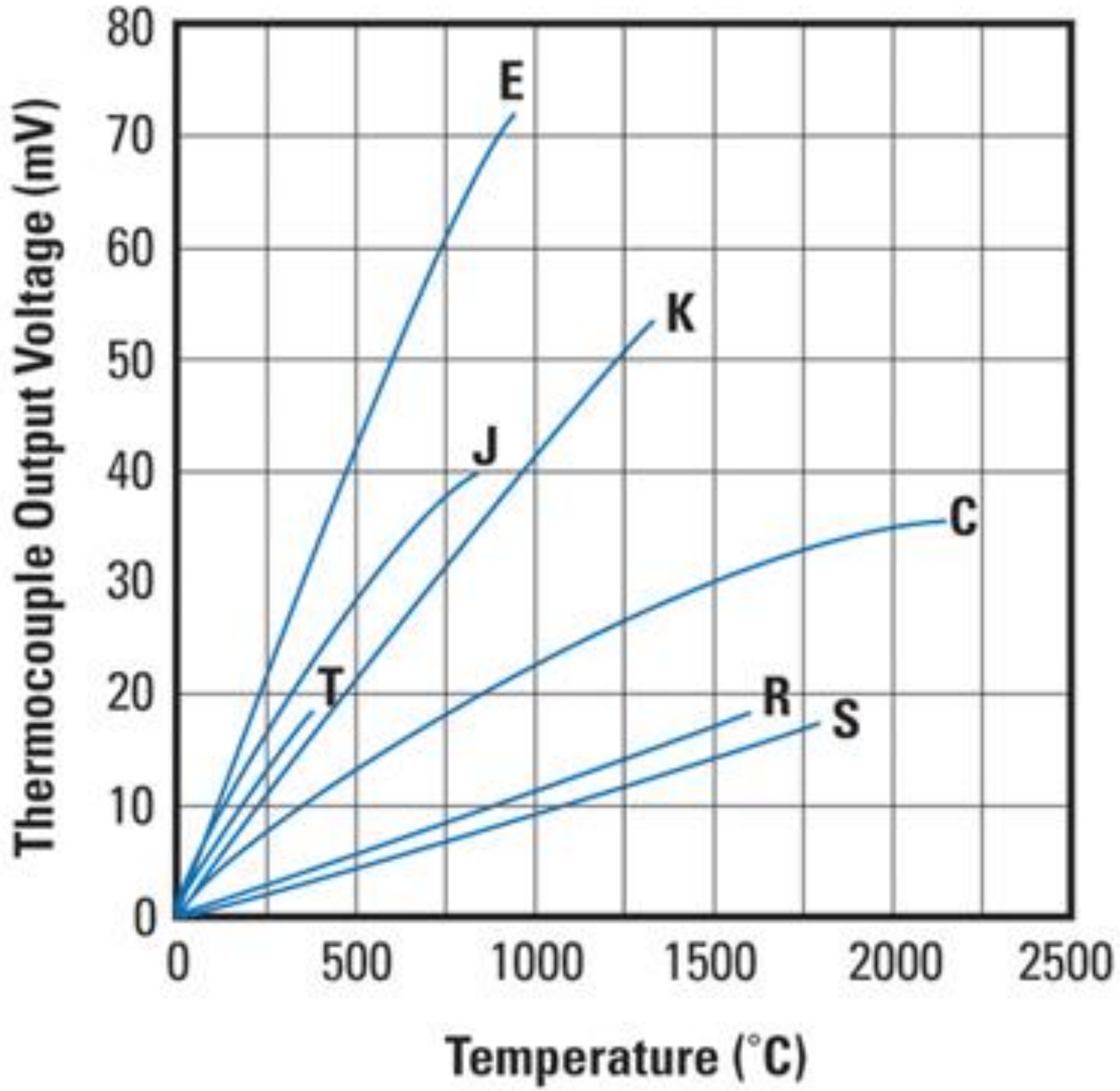
- A thermocouple works by using the movement of electrons in its metal wires when there's a temperature difference between the hot and cold ends.
- When heated, one wire becomes more negatively charged (**negative wire lead**) because its electrons move faster, while the other wire, with slower electrons, becomes less charged (**positive wire lead**).
- The difference in charge between these wires helps measure and calculate the heat at the hot end.

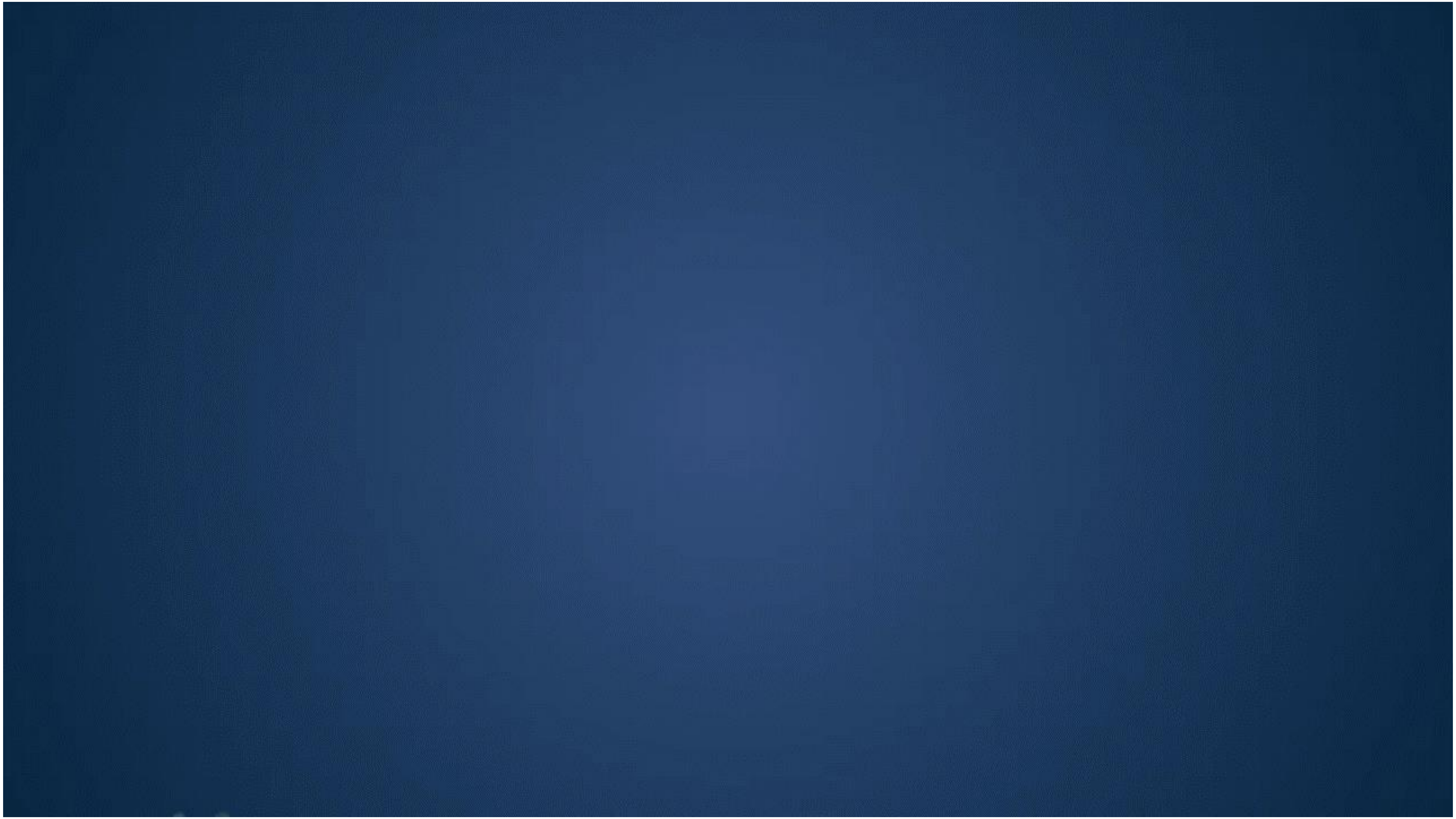


Thermocouple Types

Thermocouple Types			
Type	Conductor Combination	Temperature Range	
		°F	°C
B	Platinum 30% Rhodium / Platinum 6% Rhodium	2500 to 3100	1370 to 1700
E	Nickel-chromium / Constantan	32 to 1600	0 to 870
J	Iron / Constantan	32 to 1400	0 to 760
K	Nickel-chromium / Nickel-aluminium	32 to 2300	0 to 1260
N	Nicrosil / Nisil	32 to 2300	0 to 1260
R	Platinum 13% Rhodium / Platinum	1600 to 2640	870 to 1450
S	Platinum 10% Rhodium / Platinum	1800 to 2640	980 to 1450
T	Copper / Constantan	-75 to +700	-59 to +370

Thermocouple Types





Video Link: https://youtu.be/QOmR6IGQrxI

Thermocouple

Advantages / desadvantages

Advantages:

- Can measure temperature at a point
- Low cost
- Rugged, not easily damaged

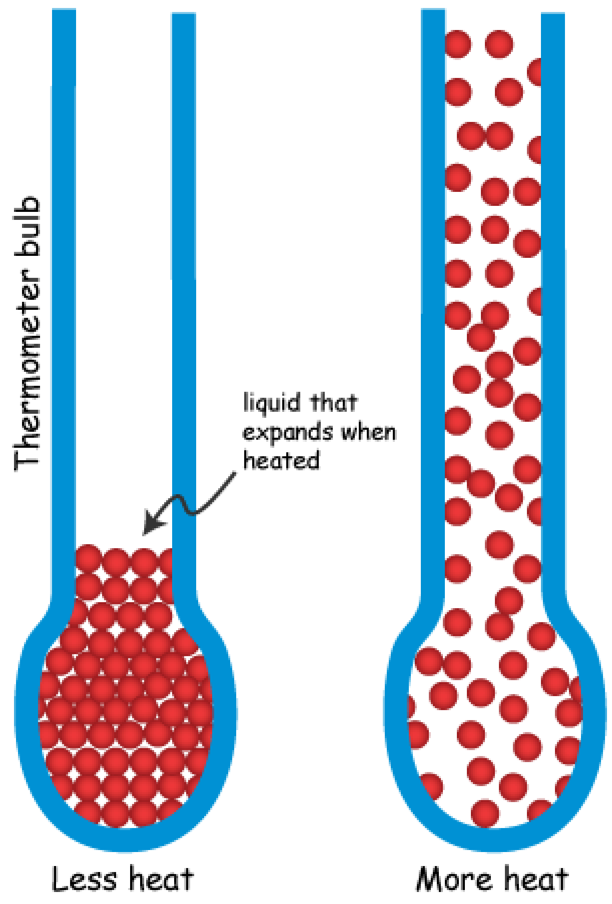
Desadvantages:

- Relatively low accuracy, degree of error is 1 deg C to 2 deg C
- Less Stable
- Prone to corrosion, due to two metals of different reactivity being in contact

Thermal Expansion devices

THERMAL EXPANSION

- Materials usually expand when heated and contract when cooled. For example, a metal rod that is heated or cooled changes in length and volume.
- The ***coefficient of linear expansion*** is the amount a unit length of a material lengthens or contracts with temperature changes.
- The ***coefficient of volumetric expansion*** is the amount a unit volume of a material expands or contracts with temperature changes.



Linear expansion ***Vs*** ***Volumetric expansion***

$$L_2 = L_1 \times \left[1 + \alpha \times (T_2 - T_1)\right]$$

where

L$_2$ = length at the final temperature

L$_1$ = length at the initial temperature

T$_2$= final temperature

T$_1$= initial temperature

α = coefficient of linear expansion

$$V_2 = V_1 \times \left[1 + \beta \times (T_2 - T_1)\right]$$

where

T$_2$= final temperature

T$_1$= initial temperature

V$_2$= volume at the final temperature

V$_1$ = volume at the initial temperature

β = coefficient of volumetric expansion

Coefficent of Thermal Expansion

TABLE 13–1 Coefficients of Expansion, near 20°C

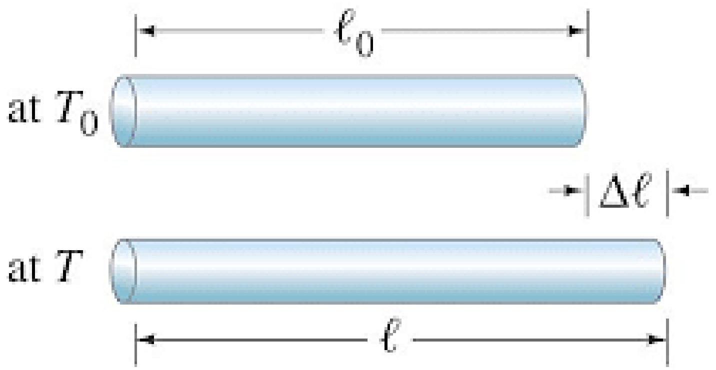
Material	Coefficient of Linear Expansion, α $(C°)^{-1}$	Coefficient of Volume Expansion, β $(C°)^{-1}$
Solids		
Aluminum	25×10^{-6}	75×10^{-6}
Brass	19×10^{-6}	56×10^{-6}
Copper	17×10^{-6}	50×10^{-6}
Gold	14×10^{-6}	42×10^{-6}
Iron or steel	12×10^{-6}	35×10^{-6}
Lead	29×10^{-6}	87×10^{-6}
Glass (Pyrex®)	3×10^{-6}	9×10^{-6}
Glass (ordinary)	9×10^{-6}	27×10^{-6}
Quartz	0.4×10^{-6}	1×10^{-6}
Concrete and brick	$\approx 12 \times 10^{-6}$	$\approx 36 \times 10^{-6}$
Marble	$1.4\text{–}3.5 \times 10^{-6}$	$4\text{–}10 \times 10^{-6}$
Liquids		
Gasoline		950×10^{-6}
Mercury		180×10^{-6}
Ethyl alcohol		1100×10^{-6}
Glycerin		500×10^{-6}
Water		210×10^{-6}
Gases		
Air (and most other gases at atmospheric pressure)		3400×10^{-6}

Coefficent of Thermal Expansion

Example:

Copper has a coefficient of linear expansion of 17.10^{-6} $(°C)^{-1}$. What is the final length of a 0.1524 meters copper strip heated from 20°C to 22°C?

Solution



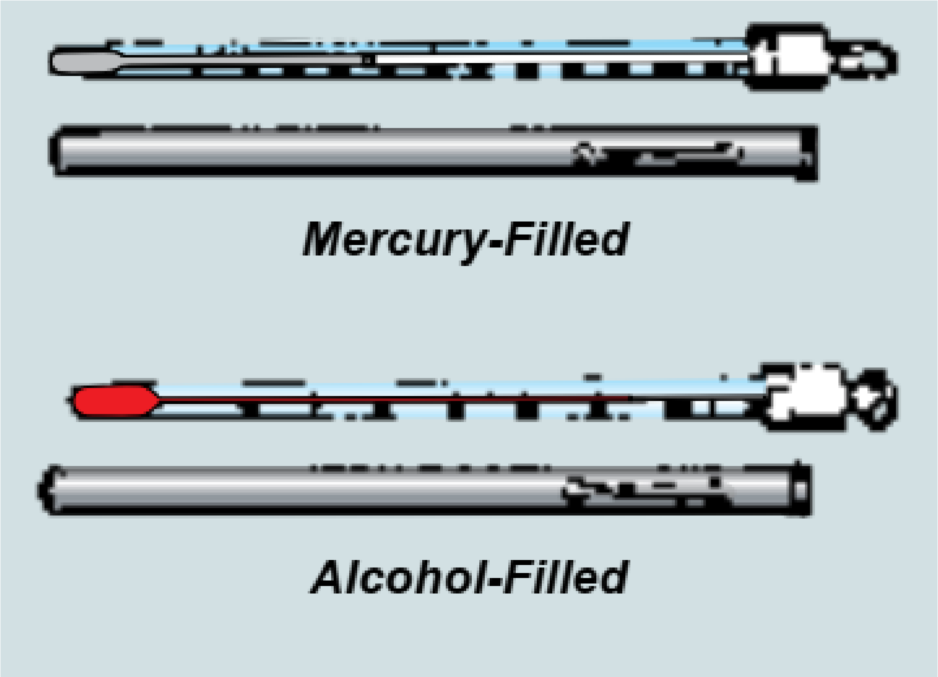
Linear expansion occurs when an object is heated.

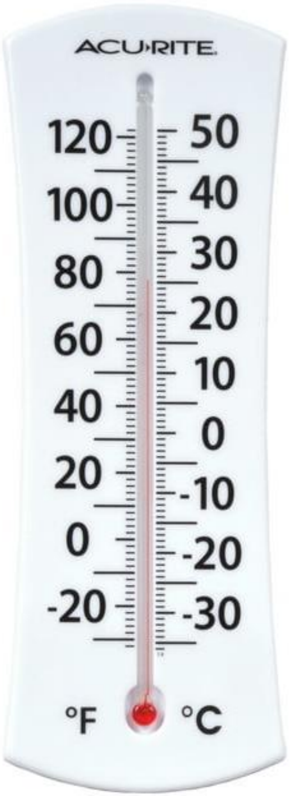
$$\ell = \ell_0(1 + \alpha \Delta T)$$

Here, α is the **coefficient of linear expansion.**

Liquid-in-glass thermometer

- The liquid in glass thermometer, is the most commonly used device to measure temperature and it is inexpensive to make and easy to use.
- A thermal expansion thermometer consisting of a sealed, narrow-bore glass tube with a bulb at the bottom filled with a liquid.

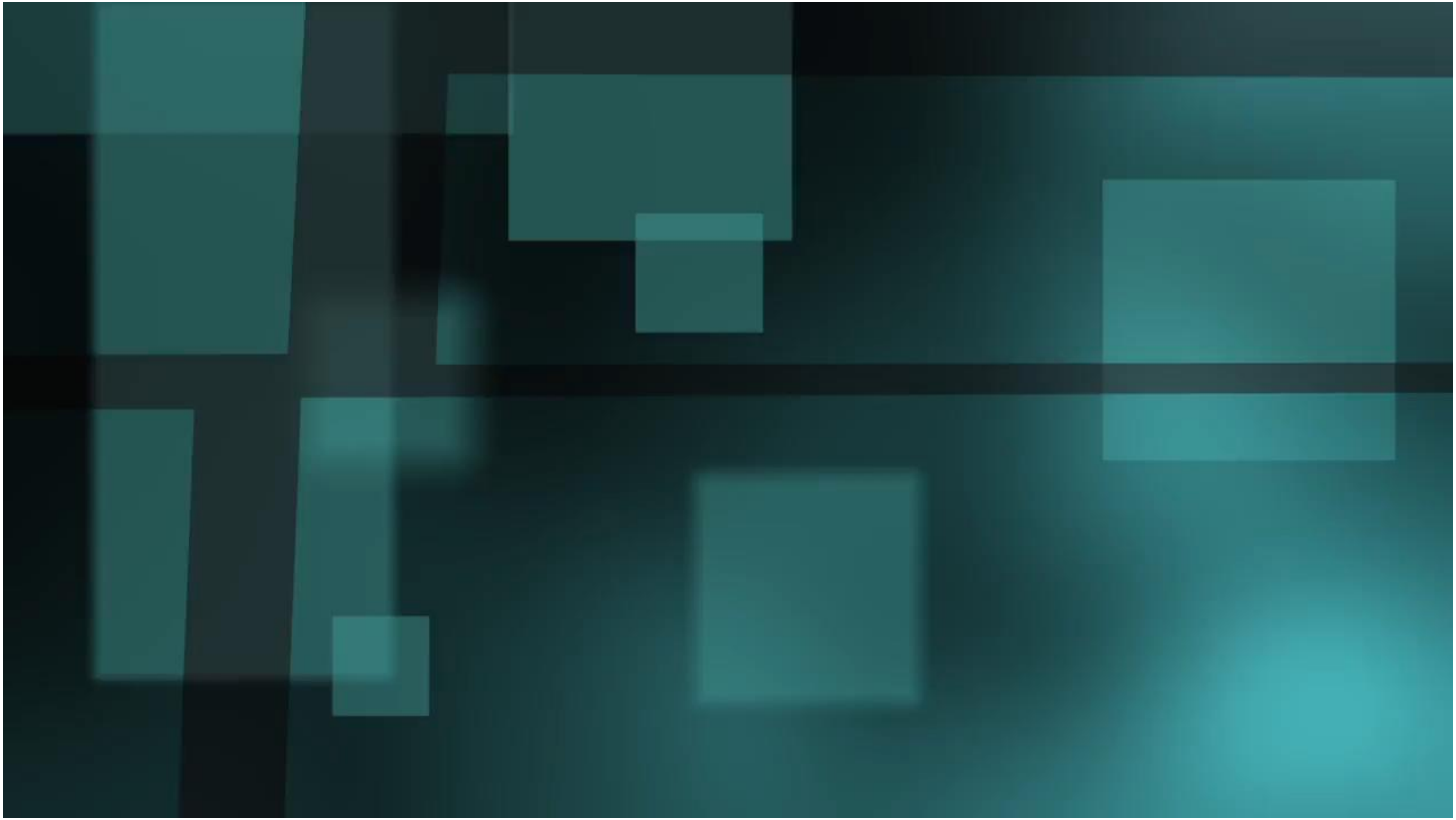




Liquid-in-glass thermometer

Liquids used in glass thermometers

Liquid	Temperature range (Celsius)
Mercury	-35 to +510
Alcohol	-80 to +70
Pentane	-200 to +30
Toluene	-80 to +100
Creosote	-5 to +200



Video Link: https://youtu.be/hognYXG29Bo

Liquid-in-glass thermometer

Advantages / desadvantages

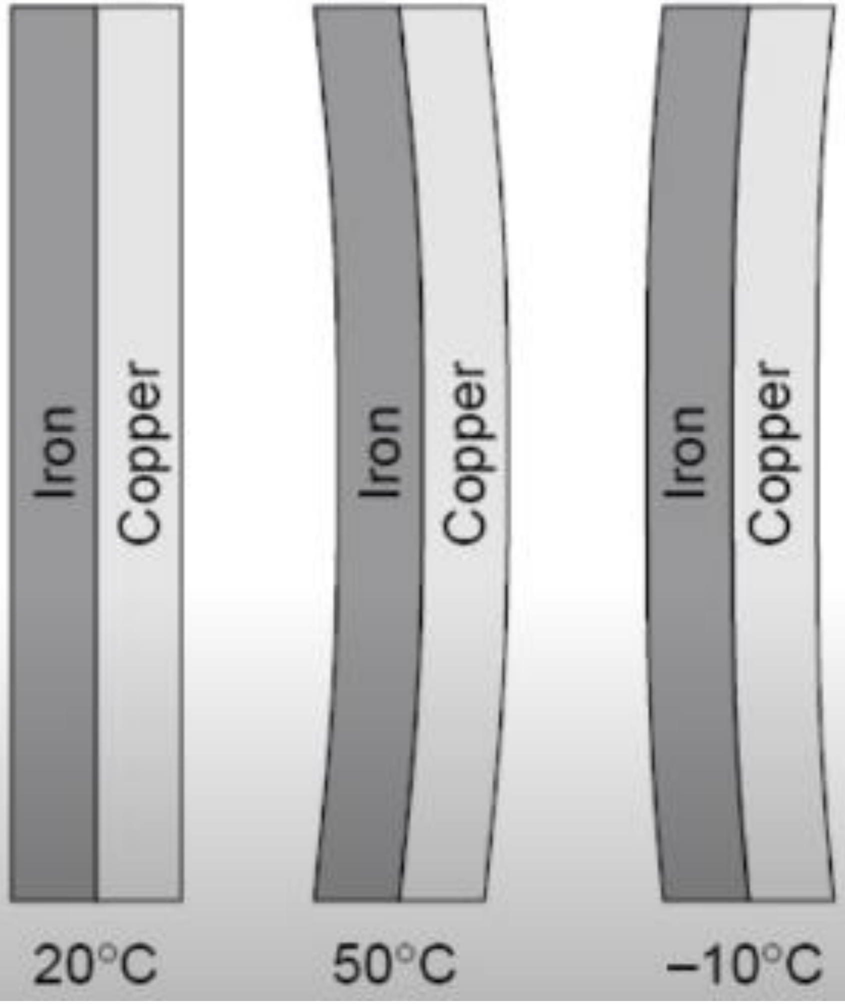
- Advantages

1) Simplicity in use & low cost.
2) Portable device.
3) Checking physical damage is easy.
4) Power source not require.

- Disadvantages

1) Can not used for automatic recording.
2) Time lag in measurement.
3) Range is limited to about 600 °C .
4) Fragile construction

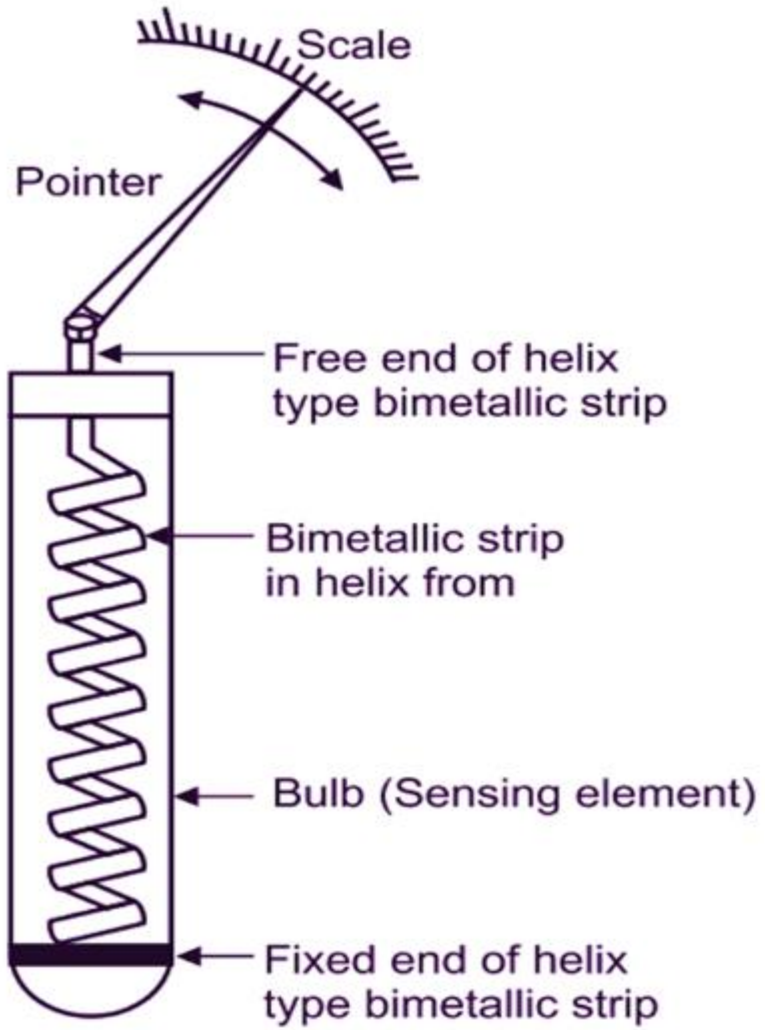
BIMETALLIC THERMOMETERS

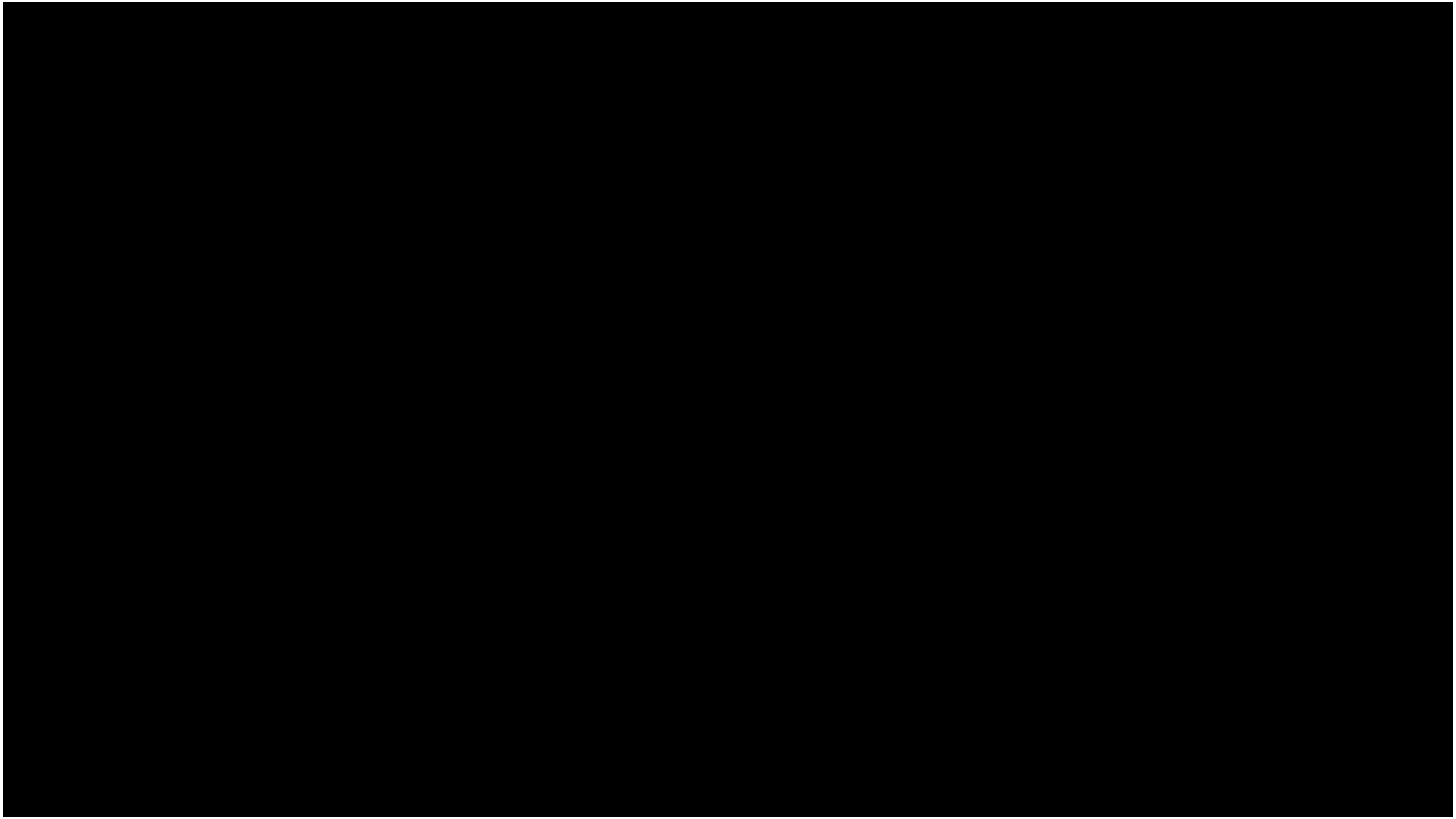


If two strips of different metals are bonded together, **any temperature change will cause the strip to bend.**

BIMETALLIC THERMOMETERS

A thermal expansion thermometer that uses a strip consisting of two metal alloys with different coefficients of thermal expansion that are fused together and formed into a single strip, and a pointer or indicating mechanism calibrated for temperature reading.





Video Link: https://youtu.be/82FPQ6z8vcE

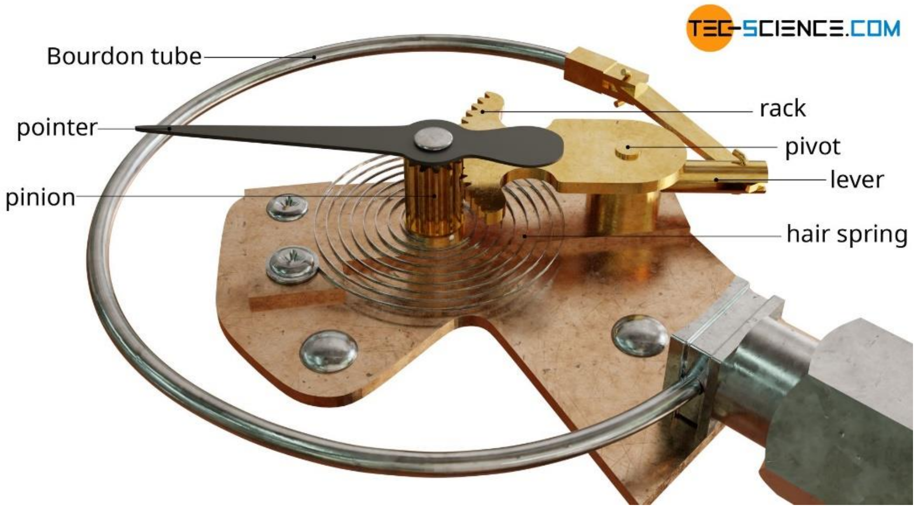
Gas-In-Metal Thermometers

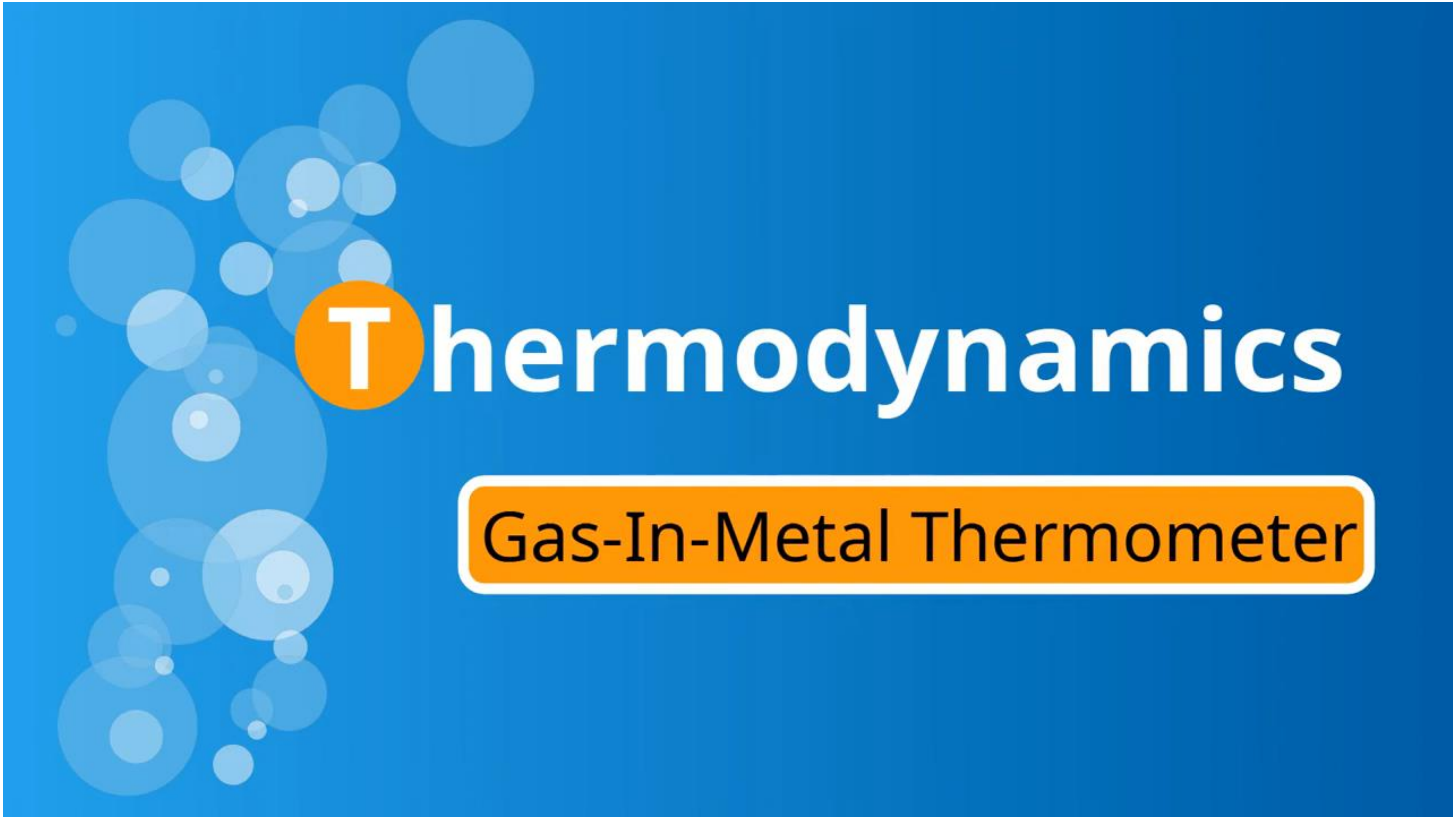
A ***Gas-In-Metal Thermometers*** is a pressure-spring thermometer that measures the increase in pressure of a confined gas (kept at constant volume) due to a temperature increase.

Nitrogen is the gas most often used for such systems because it is chemically inert and possesses a favorable coefficient of thermal expansion.

The Boyle's law;

$$PV = KT$$



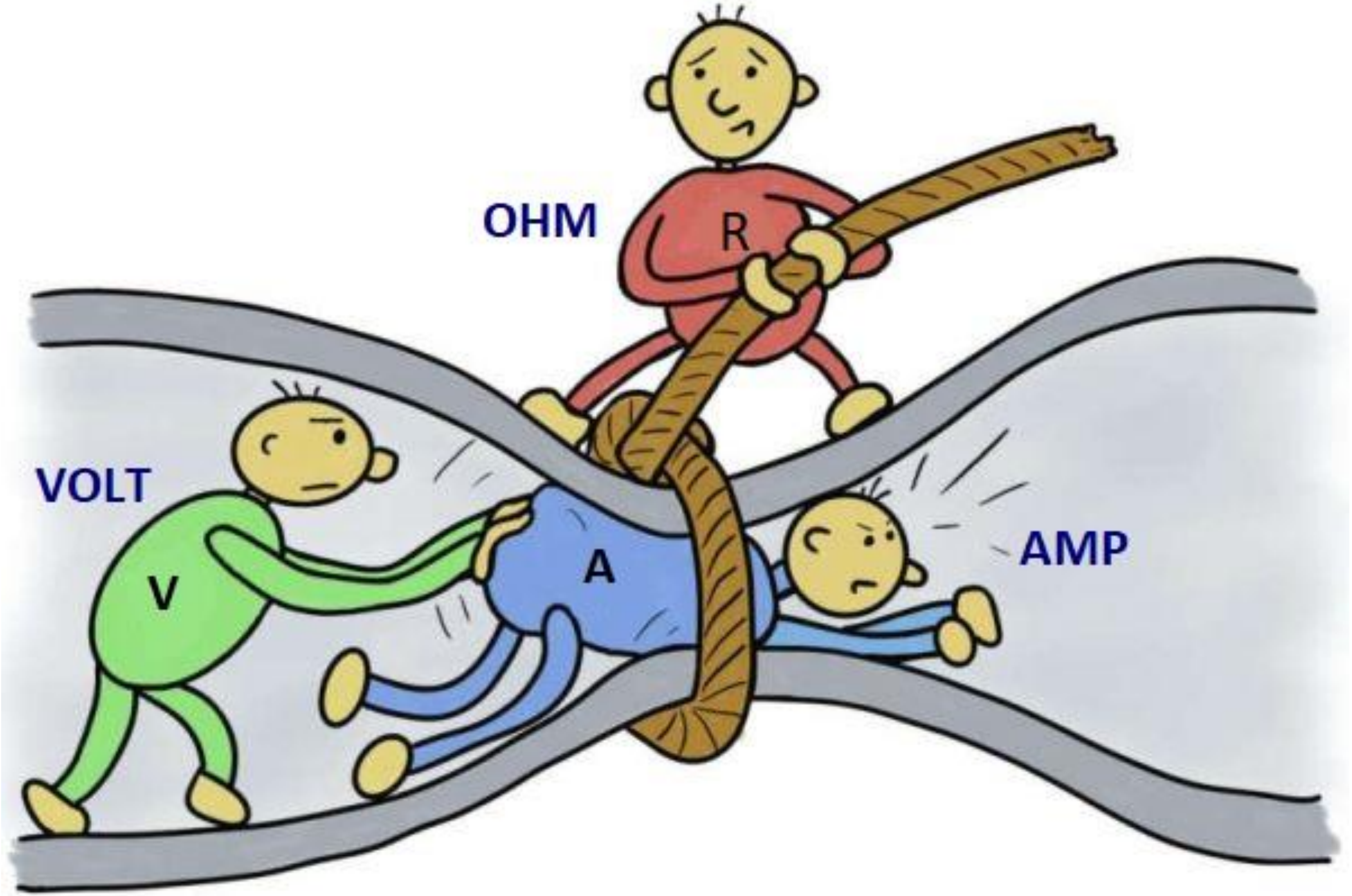


Video Link: https://youtu.be/aYpHDEhvzLo

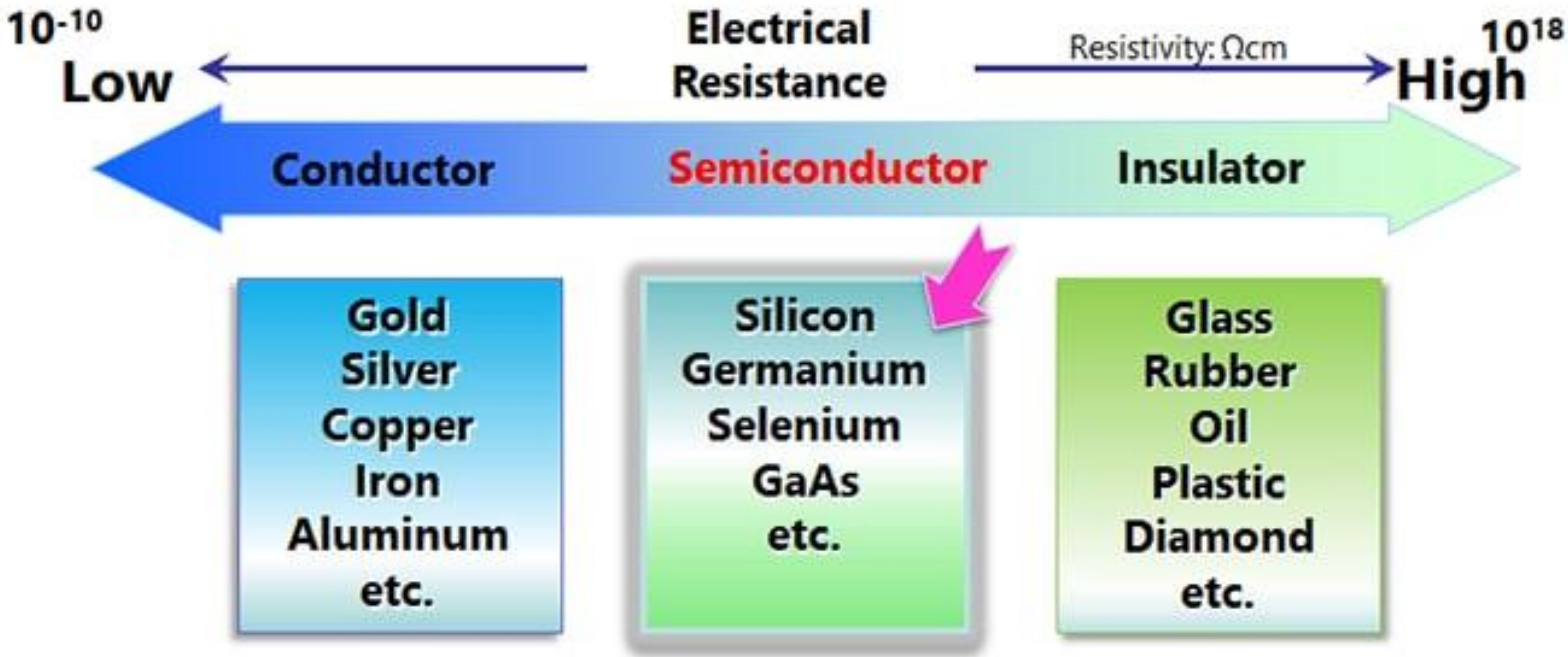
Video Link: https://youtu.be/Vjse8sS800w

Resistance Thermometers

Resistance



Conductors Vs Semiconductor Vs Insulator

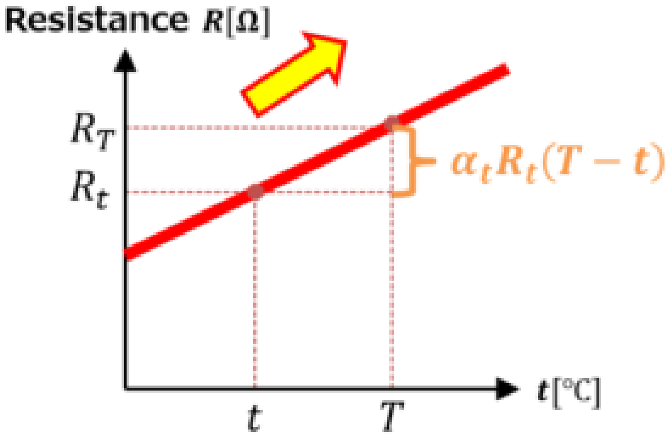


Resistance Temperature Characteristics

$$R_T = R_t + \alpha_t R_t (T - t)$$
$$= R_t \{1 + \alpha_t (T - t)\}$$

- R_T: Resistance at temperature T[℃]
- R_t: Resistance at temperature t[℃]
- α_t: Temperature coefficient of resistance.

Metals($\alpha_t > 0$)

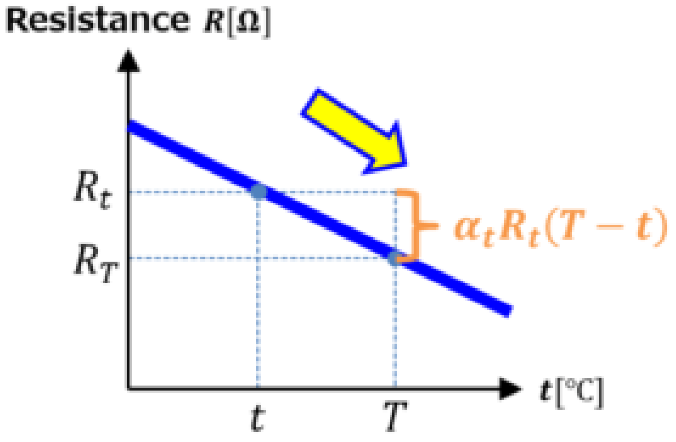


$$R_T = R_t + \alpha_t R_t (T - t)$$
$$= R_t \{1 + \alpha_t (T - t)\}$$

Positive Positive

The resistance increases as the temperature increases.

Semiconductors($\alpha_t < 0$)



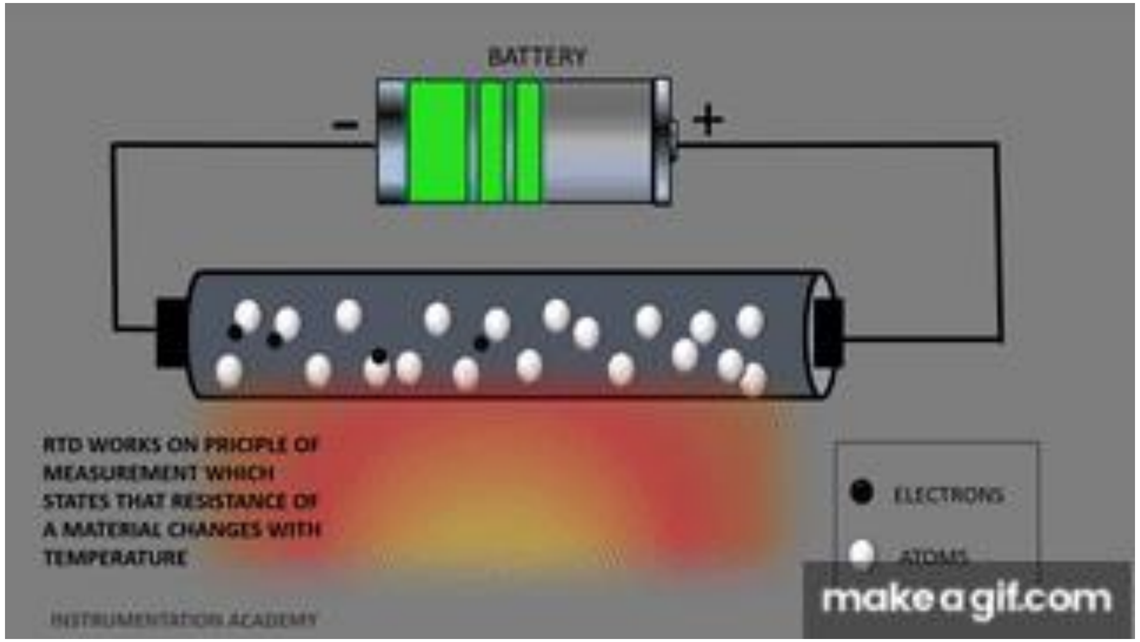
$$R_T = R_t + \alpha_t R_t (T - t)$$
$$= R_t \{1 + \alpha_t (T - t)\}$$

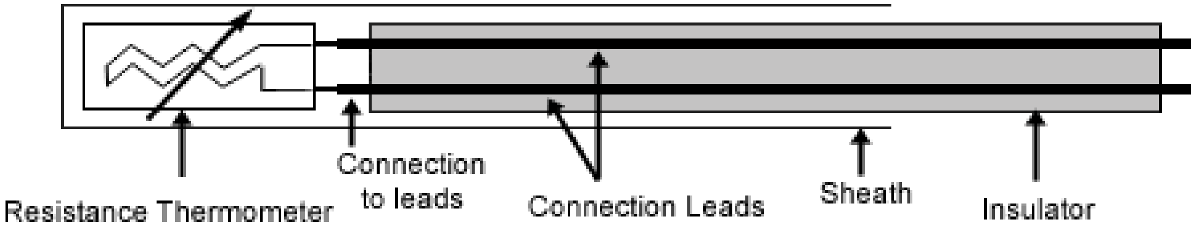
Negative Positive

The resistance decrease as the temperature increases.

Resistance Temperature Detectors (RTD)

Resistance temperature detector (RTD): An electrical thermometer consisting of a high-precision resistor with resistance that varies with temperature, a voltage or current source, and a measuring circuit.





Resistance Temperature Detectors (RTD)

$$R = R_0(1+\alpha T)$$

R_0 : the resistance of the sensor at 0°C

R : the resistance of the sensor at t °C

α : temperature coefficient of resistance

Rely on the principle that **the resistance of a metal varies with temperature** according to the relationship between resistance change and temperature.

Platinum wire is the best material for an RTD because it is useful over a wide temperature range from -200 to 650 ºC.

Video Link: https://youtu.be/WNs8FBl3c7M

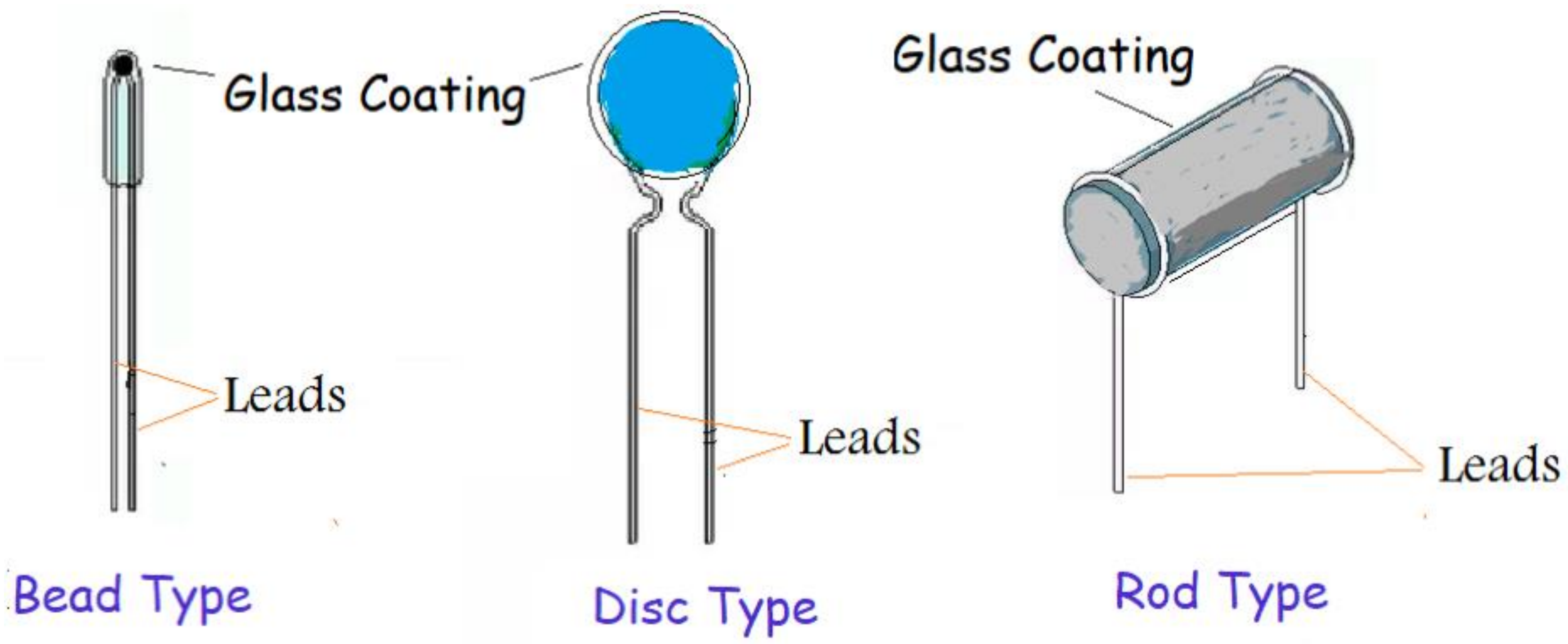
Resistance Temperature Detectors (RTD)

Advantages / desadvantages

Advantages	Disadvantages
• Linear output • Better stability	• Self heating • Less sensitive • Cost

Thermistors

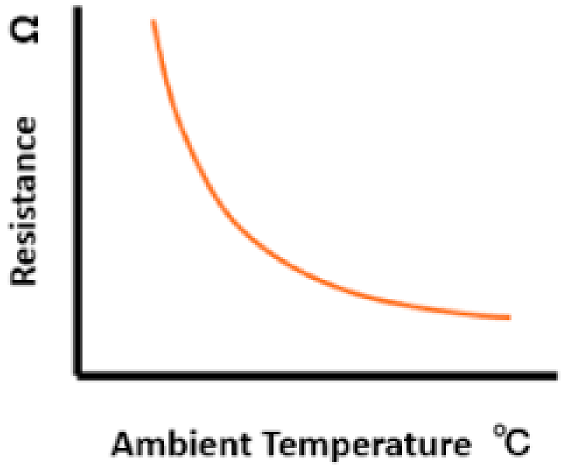
Thermistor: A temperature-sensitive resistor consisting of solid-state semiconductors made from sintered metal oxides and lead wires, hermetically sealed in glass.

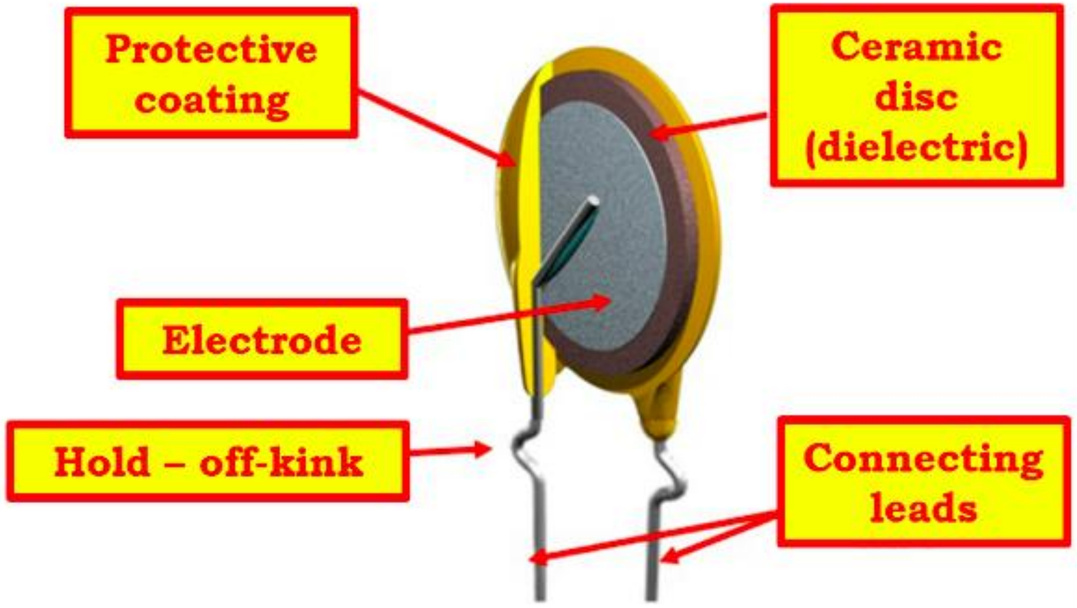


Thermistors

Construction of Thermistor

- Thermistors are made up of sintered mixtures of metal oxides like manganese, nickel, cobalt, and iron.
- The resistance of thermistors varies **from 0.4 ohms to 75 mega-ohms.**
- Thermistors are fabricated in **different shapes** and **sizes**.
- Thermistors has **Negative temperature coefficient of resistance**





Thermistors Vs RTD

Video Link: https://youtu.be/qx97WYaURNA

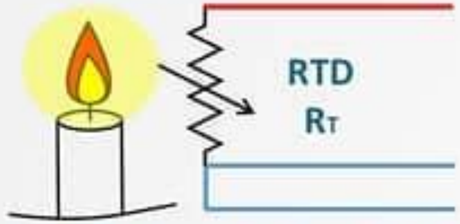
Thermistors

Advantages / desadvantages

ADVANTAGES	DISADVANTAGES
Fast	Non-Linear
Small	Excitation Required
Two-Wire	Limited Temperature Range
Inexpensive	Self-Heating
	Fragile

RTD Vs Thermistors Vs Thermocouple

RTD



$R_T = R_0 (1 + \alpha (T - T_0))$

Output is Change in Resistance

External Power Supply Required

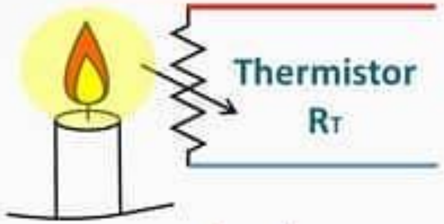
Linear Relationship

Range = -200 °C To 800 °C

Moderate Sensitivity

Moderate Accuracy (0.1 °C)

THERMISTOR



$R_T = R_0 e^{\beta (\frac{1}{T} - \frac{1}{T_0})}$

Output is Change in Resistance

External Power Supply Required

Exponential Relationship

Range = -100 °C To 150 °C

High Sensitivity

High Accuracy (0.05 °C)

THERMOCOUPLE

$V_0 = K (T_{Hot} - T_{Ref})$

Output is Change in Voltage

Self Powered

Slightly Non-Linear Relationship

Range = -200 °C To 1800 °C

Low Sensitivity

Low Accuracy (0.5 °C)

Radiative Heat Emission

Pyrometer

- Radiation thermometers, or pyrometers, make use of the fact that **all objects emit thermal radiation**, as seen when looking at the bars of an electric fire or a light bulb.

- The amount of radiation emitted can be measured and related to temperature using the **Planck law of radiation**.

- Temperatures can be measured remotely using this technique, with the sensor situated some distance away from the object. Hence, it is **useful for objects that are very hot, moving or in hazardous environments.**

Video Link: https://youtu.be/CcBPy9tQeYc

MCQ questions

MCQ questions

1. Thermocouple working principle based on the

a) Seeback effect

b) Peltier effect

c) Thompson effect

d) All of the above

MCQ questions

2. The temperature of steam at around 540ºC can be measured by

a) thermometer

b) radiation pyrometer

c) thermopile

d) thermocouple

MCQ questions

3. A thermocouple is used to measure:

a) Voltage

b) High temperatures

c) Potential difference

d) Low temperatures

e) Pressure

MCQ questions

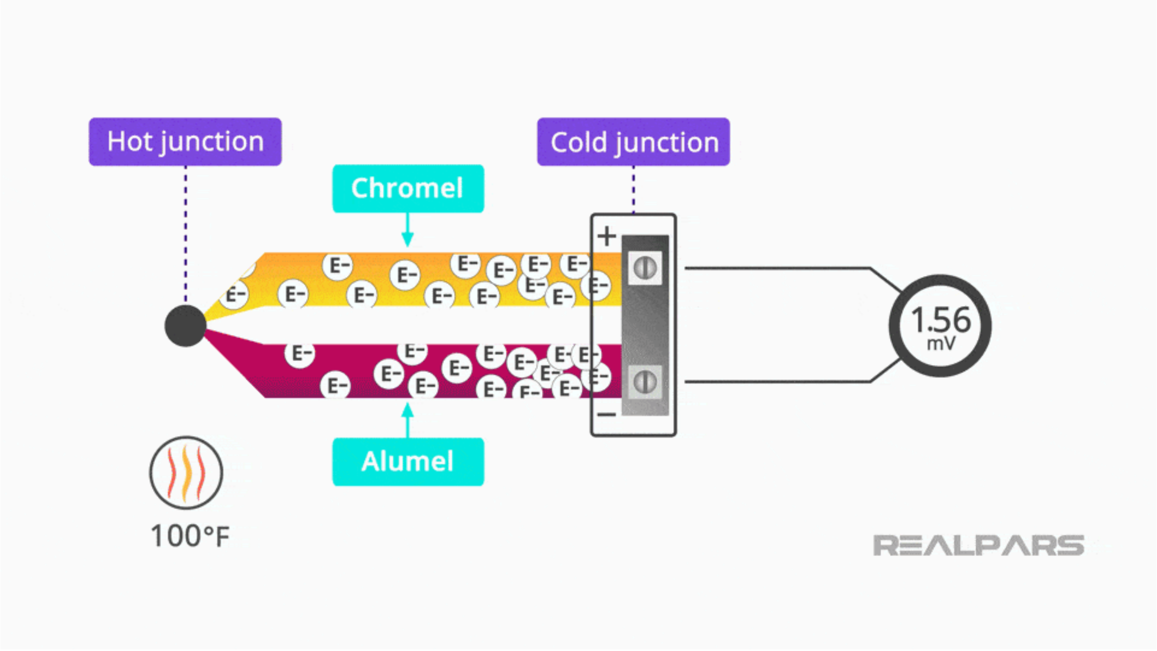
4. What happens when heat is applied to the joined ends of wires of thermocouple?

a) the wires contract

b) the wires start to rotate

c) a small voltage is generated

d) the wires separate



MCQ questions

5. Iron-Constantan thermocouple is commercially known as ______________ thermocouple.

a) J-type

b) E-type

c) K-type

d) T-type

Thermocouple Types			
Type	Conductor Combination	Temperature Range	
		°F	°C
B	Platinum 30% Rhodium / Platinum 6% Rhodium	2500 to 3100	1370 to 1700
E	Nickel-chromium / Constantan	32 to 1600	0 to 870
J	Iron / Constantan	32 to 1400	0 to 760
K	Nickel-chromium / Nickel-aluminium	32 to 2300	0 to 1260
N	Nicrosil / Nisil	32 to 2300	0 to 1260
R	Platinum 13% Rhodium / Platinum	1600 to 2640	870 to 1450
S	Platinum 10% Rhodium / Platinum	1800 to 2640	980 to 1450
T	Copper / Constantan	-75 to +700	-59 to +370

www.Control and Instrumentation.com

MCQ questions

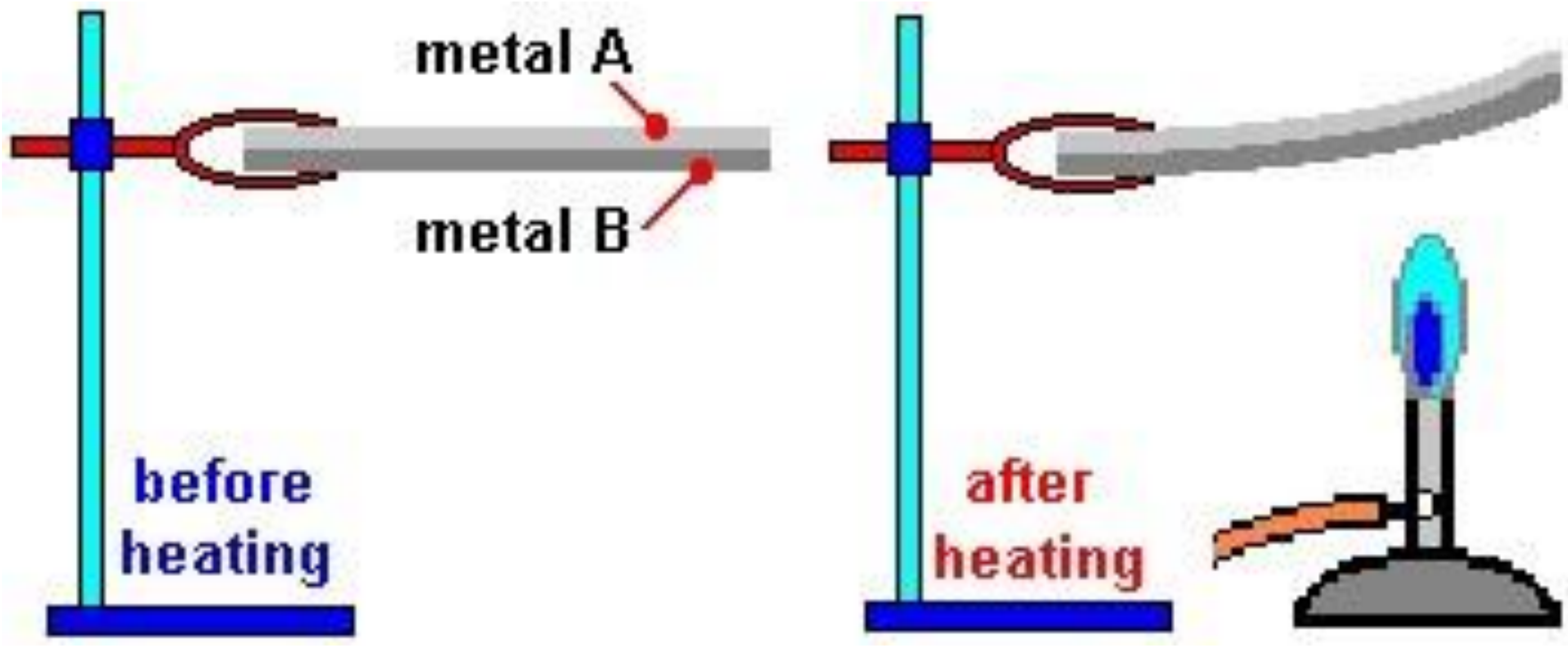
6. The output of a Bimetallic thermometer will be ____________

(a) Strain

(b) Pressure

(c) Displacement

(d) Voltage



MCQ questions

7. Which of the following can be used for measuring Temperature ?

(a) Metallic Diaphragm

(b) Fluid Expansion System

(c) Capsule

(d) Bourdon tube

MCQ questions

8. Convert a temperature measurement of 250°C into Kelvin.

(a) 523 K

(b) 209 K

(c) 709 K

(d) -23 K

MCQ questions

9. Resistance Temperature Detector (RTD) is ____________

(a) An electrical thermometer

(b) A mechanical Transducer

(c) A chemical Transducer

(d) A physical Transducer

MCQ questions

10. In Optical Pyrometer Temperature is measured by

(a) Photocell Principle

(b) Thermocouple Effect

(c) Comparing the brightness of the source with the brightness of a standard source

(d) None of the above

MCQ questions

11. Bimetallic strips are employed in ____________ thermometers.

(a) Vapour pressure

(b) Liquid-expansion

(c) Metal Expansion

(d) Resistance

MCQ questions

12. Liquid expansion thermometers are filled with ______________

(a) Mercury

(b) Amalgam

(c) Gallium

(d) Cesium

MCQ questions

13. A Radiation pyrometer is based on ____________

(a) Planck's Law

(b) Stefan-Boltzmann law

(c) Rayleigh-jeans law

(d) Sakuma-Hattori equation

- The amount of radiation emitted can be measured and related to temperature using the **Planck law of radiation**.

MCQ questions

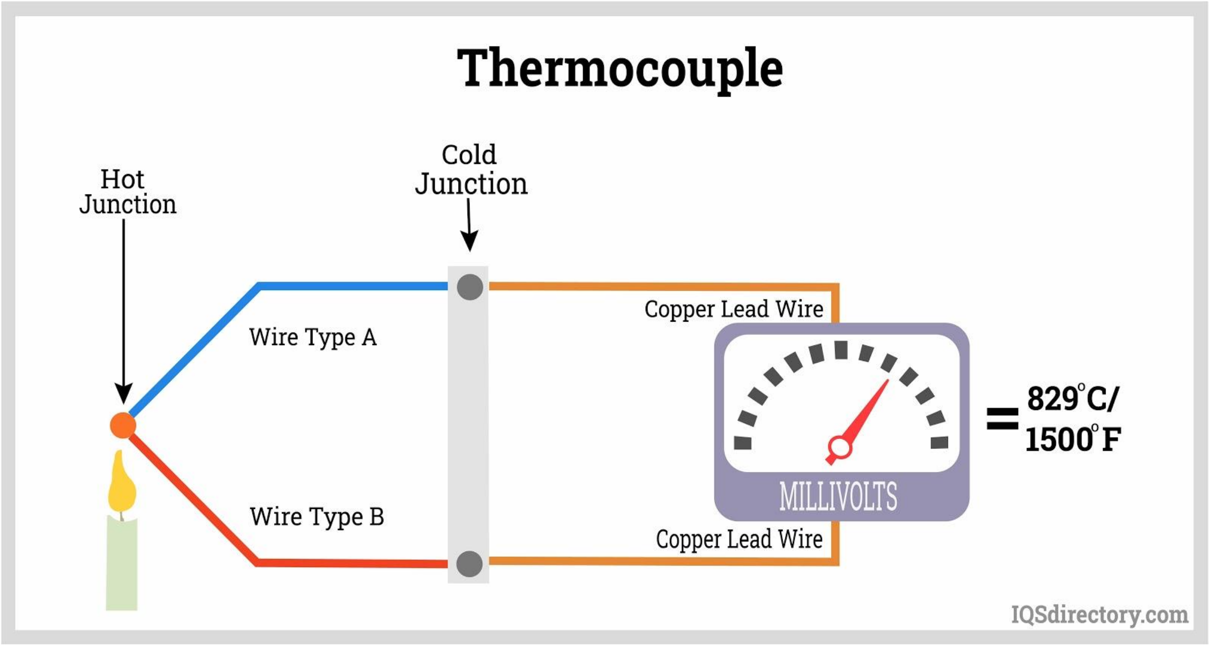
14. A Thermocouple thermometer consists basically of

(a) 1 Wire

(b) 2 Wires

(c) 3 Wires

(d) 4 Wires



MCQ questions

15. Convert 100 °C into °F

(a) 212°F

(b) 100°F

(c) 180°F

(d) 200°F

CELSIUS TO FAHRENHEIT

$$T_F = \left(\frac{9}{5} T_C\right) + 32$$

FAHRENHEIT TO CELSIUS

$$T_C = \frac{5}{9}\left(T_F - 32\right)$$

MCQ questions

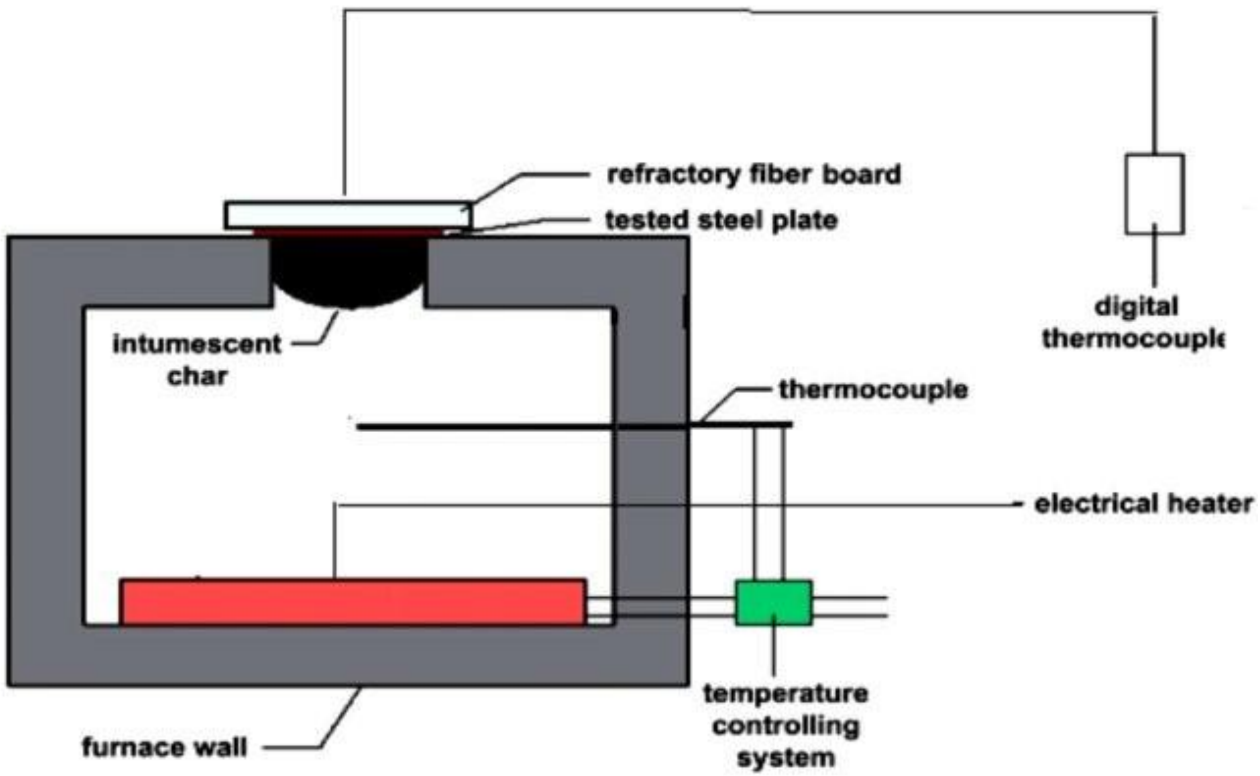
16. For measuring the temperature of a furnace which is most suitable instrument?

(a) Resistance thermometer

(b) Thermocouple

(c)Optical Pyrometer

(d)Bimetallic thermometer



MCQ questions

17. Thermocouples is suitable for measuring

(a)Liquid temperature only

(b)Very high temperature only

(c)Very low temperature only

(d)Both high & Low temperature

MCQ questions

18. Which thermocouple can be used to measure temperature around 1400°C?

(a) Type T

(b) Type E

(C) Type R

(d) Type K

Thermocouple Types			
Type	Conductor Combination	Temperature Range	
		°F	°C
B	Platinum 30% Rhodium / Platinum 6% Rhodium	2500 to 3100	1370 to 1700
E	Nickel-chromium / Constantan	32 to 1600	0 to 870
J	Iron / Constantan	32 to 1400	0 to 760
K	Nickel-chromium / Nickel-aluminium	32 to 2300	0 to 1260
N	Nicrosil / Nisil	32 to 2300	0 to 1260
R	Platinum 13% Rhodium / Platinum	1600 to 2640	870 to 1450
S	Platinum 10% Rhodium / Platinum	1800 to 2640	980 to 1450
T	Copper / Constantan	-75 to +700	-59 to +370

MCQ questions

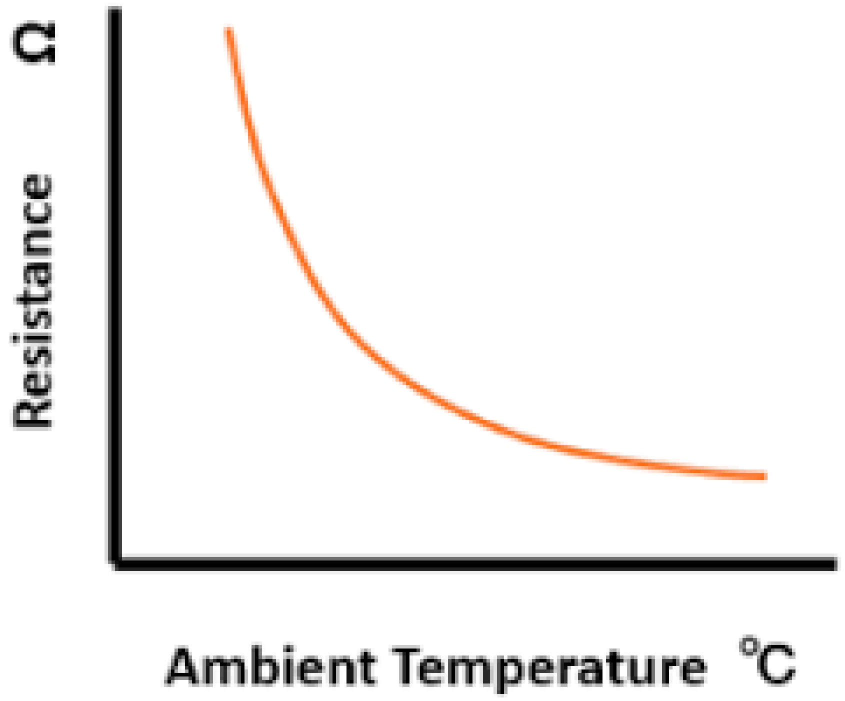
19. Thermistor has

(a)Negative temperature coefficient of resistance

(b)Positive temperature coefficient of resistance

(c)Null coefficient of resistance

(d)None of these



MCQ questions

20. Resistance of Thermistor depends on

(a) Temperature

(b) Voltage

(c) Current

(d) None of these

MCQ questions

21. Identify the thermocouple type with the highest temperature limit

(a) S type

(b) J type

(c) K type

(d) T type

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