FACULTY OF MECHANICAL ENGINEERING

# SKMM 1912 EXPERIMENTAL METHODS

UNIVERSITI TEKNOLOGI MALAYSIA

# MEASUREMENT OF TEMPERATURE

# CONCEPT AND DEFINITIONS

- Temperature is related to **heat**
- Measuring temperature means measuring heat
- Heat is measured using the concept of heat **equilibrium**
  - i.e heat on the measuring equipment is brought to the same heat of the measured item

# SOME HISTORY

In 1593, **Galileo Galilei** invented a rudimentary water thermometer (using the contraction of air to draw water up a tube).

# HOW TO MEASURE TEMPERATURE

**Six types** of equipment:

1. thermocouples
2. resistive temperature devices (RTDs) and thermistors
3. infrared radiators
4. bimetallic devices
5. liquid expansion devices
6. change-of-state devices

# TEMPERATURE SCALE

The **two scales** commonly in use today dated back from the eighteenth century and are named after Gabriel Daniel Fahrenheit and the Swedish astronomy professor Anders Celsius.

**Fahrenheit** designed his scale to have two reference points that could be set up in his workshop.

He originally chose the **melting point of pure ice and the temperature of a normal human body**, which he took as being 32° and 96° respectively.

# TEMPERATURE SCALE – fahrenheit

These conveniently gave positive values for all the temperatures he encountered.

**Later he changed to using the boiling point of water (212°)** as the upper fixed point of the scale.

# TEMPERATURE SCALE - celsius

**Celsius** also used the ice and steam points, but took them to be **0 °C and 100 °C** respectively.

Although the Celsius scale has taken precedence over the Fahrenheit scale, the latter is still familiar in weather reports in the United Kingdom: a summer's day temperature of 75 °F seems much more pleasant than one of 24 °C!

# TEMPERATURE SCALE – kelvin

A **third**, fundamental, temperature scale was proposed in 1854 by the Scottish physicist William Thomson, Lord **Kelvin**.

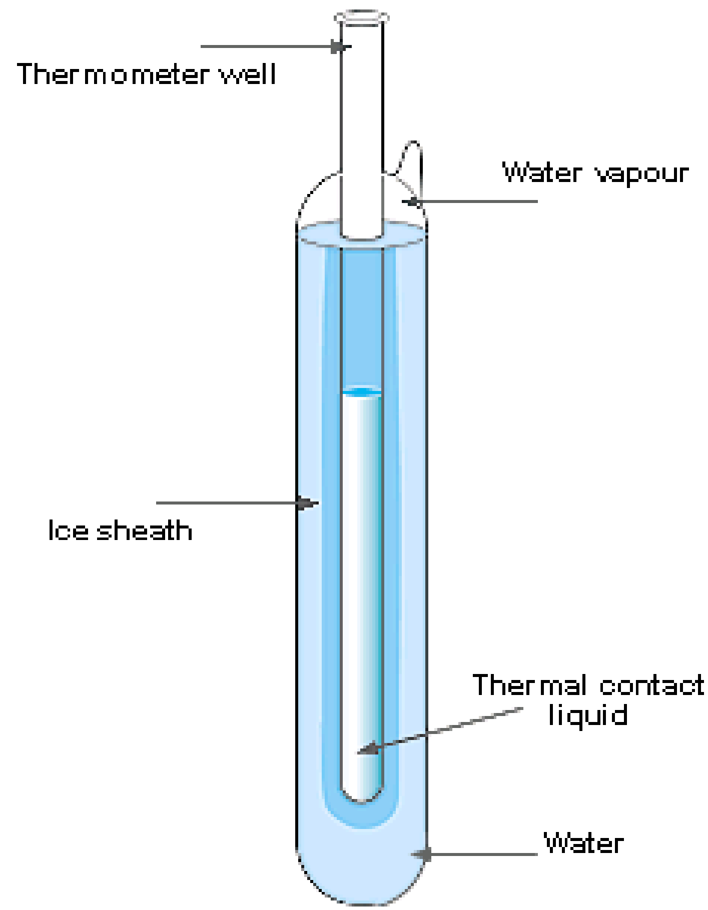
It is based on the idea of the **absolute zero, the point of no discernible energy**, which is independent of any particular material substance.

The Kelvin scale is widely used by physicists and engineers to determine and apply fundamental laws of thermodynamics.

# TEMPERATURE SCALE – kelvin

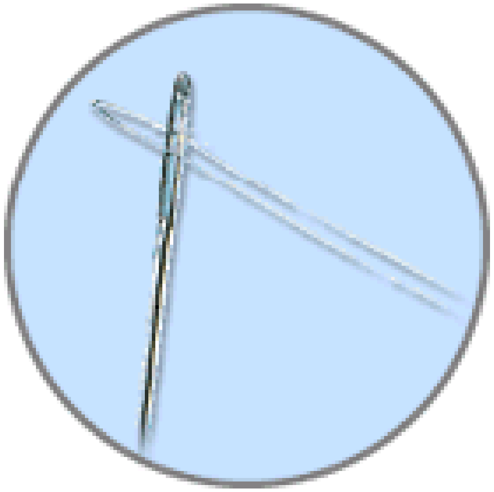
*The Intenational Temperature Scale of 1990 (the ITS-90)*

Since 1954 the unit of (thermodynamic) temperature has been defined as the kelvin, and is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water. This is the unique temperature and pressure at which the three phases of water (solid, liquid and vapour) co-exist in equilibrium. It is fractionally higher than the melting point, being 0.01 °C or 273.16 K. From this single point it is possible to generate a thermodynamic temperature scale using gas thermometers and radiation thermometers which accurately obey known laws.




**Triple point of water cell - definition of the Kelvin**

# TEMPERATURE MEASUREMENT -Thermocouple



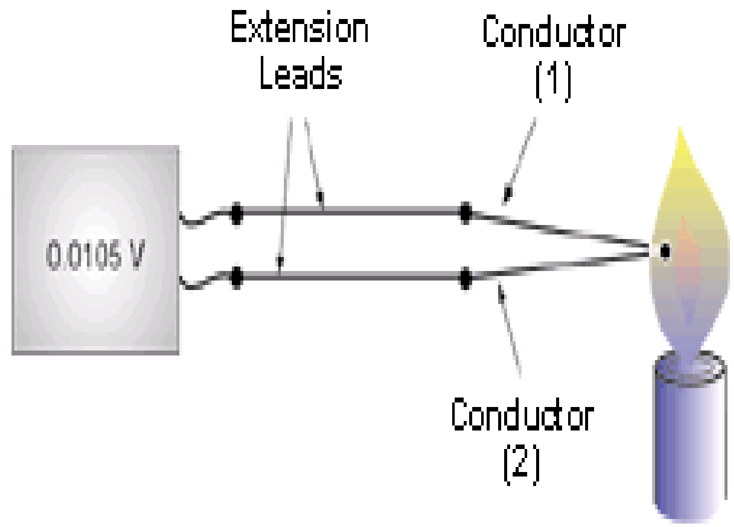
SH Temperature Measurement Sensors

Thermocouple consists of **two strips of wires** made of different metals and joined at one end. Changes in the temperature at that juncture induce a change in electromotive force (**emf**) between the other ends. As temperature goes up, this output emf of the thermocouple rises, though not necessarily linearly

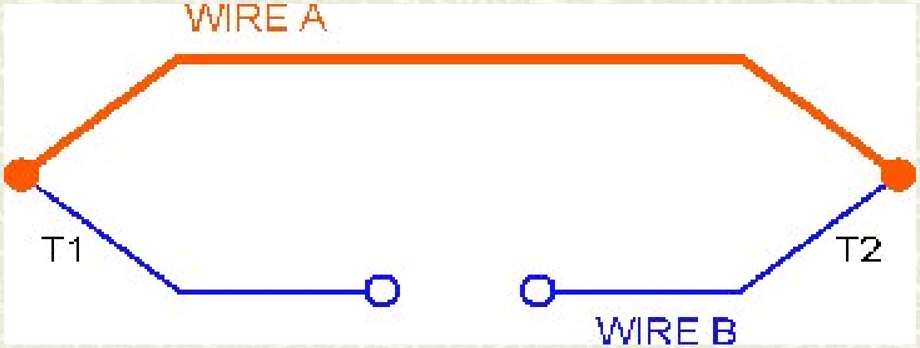
# TEMPERATURE MEASUREMENT -Thermocouple

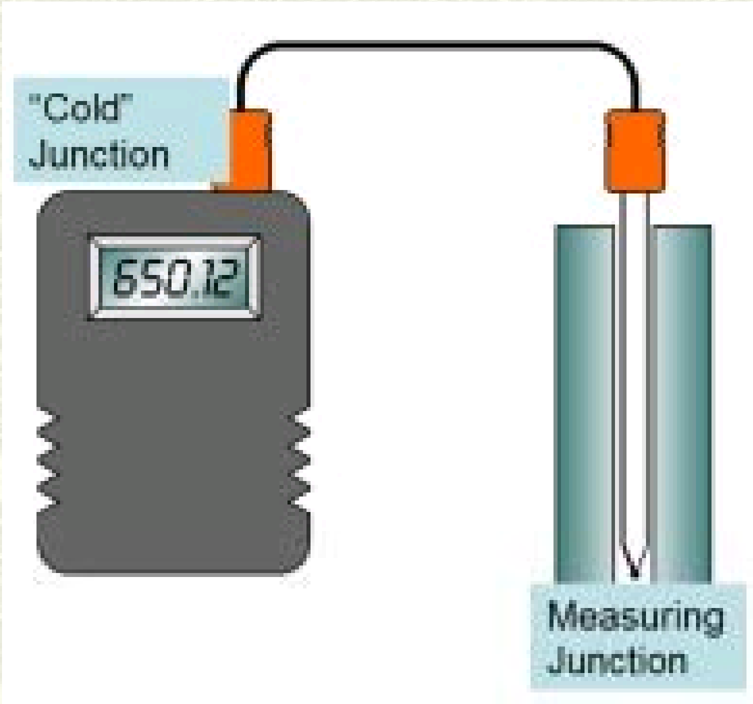
- Thermocouples

Thermocouples are the most common sensors in industrial use. They have a long history, the original paper on thermoelectricity by Seebeck being published in 1822. They consist of two dissimilar metallic conductors joined at the point of measurement. When the conductors are heated a voltage is generated in the circuit, and this can be used to determine the temperature.



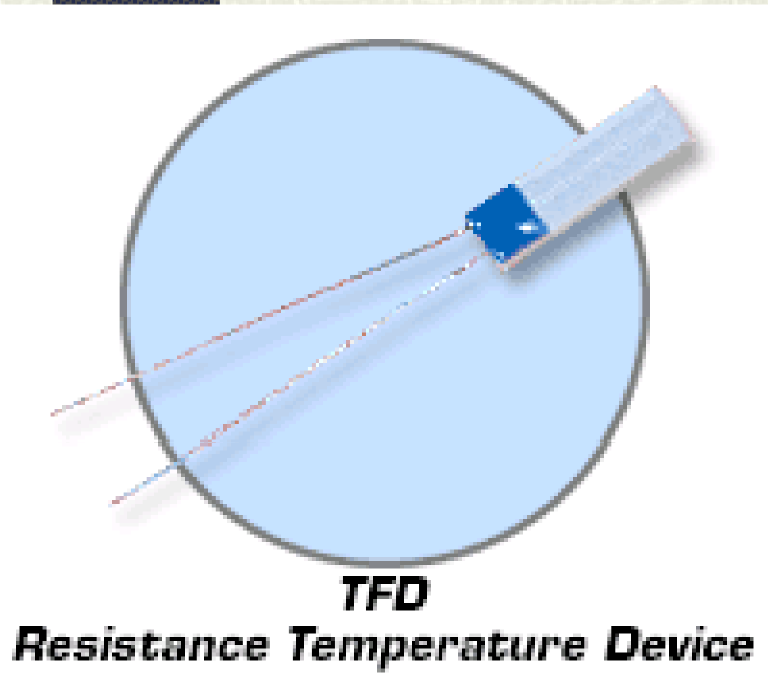
# TEMPERATURE MEASUREMENT -Thermocouple



# TEMPERATURE MEASUREMENT

## -Resistance Temperature Devices




•Resistive temperature devices capitalize on the fact that the electrical resistance of a material changes as its temperature changes.

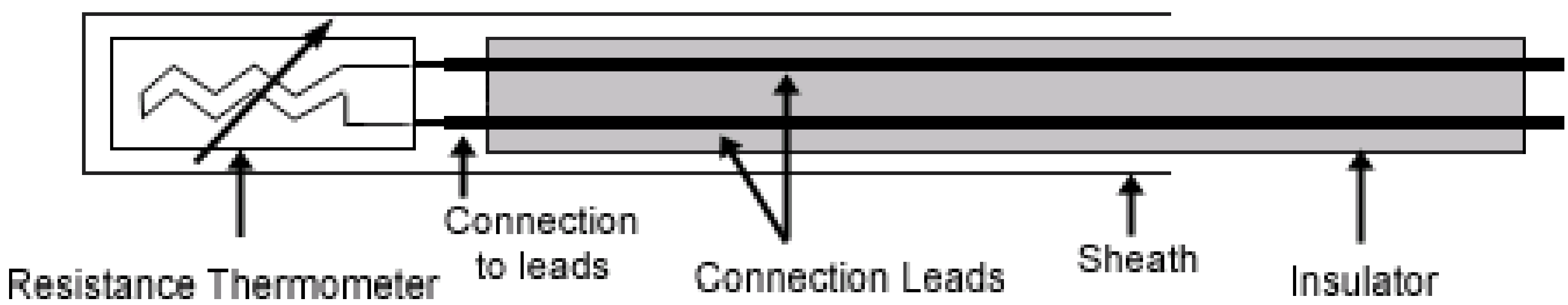
•Two key types are the **metallic devices** and **thermistors**.

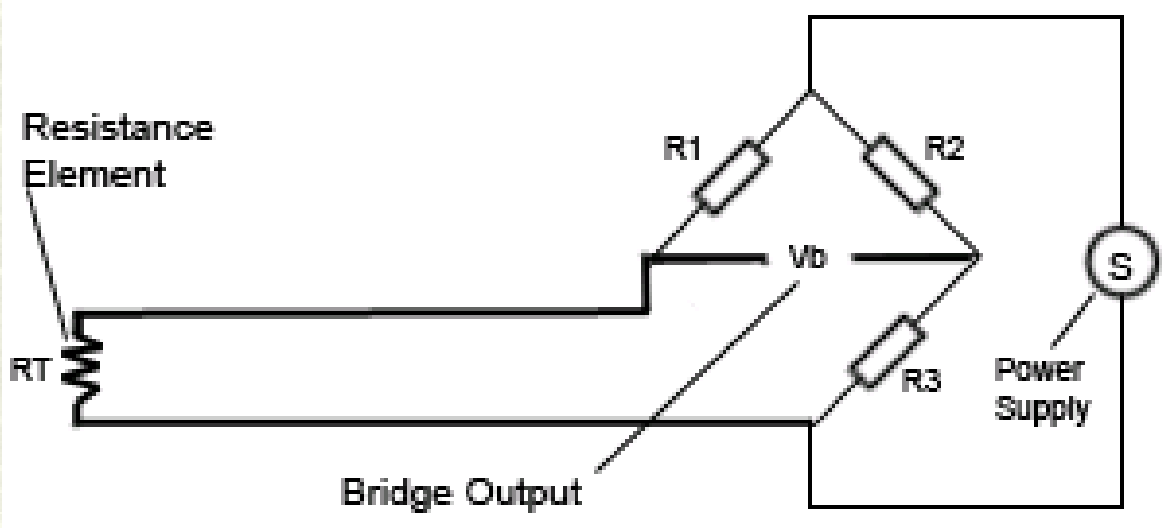
•As their name indicates, RTDs rely on resistance change in a metal, with the resistance rising more or less linearly with temperature.

•Thermistors are based on resistance change in a ceramic semiconductor; the resistance drops nonlinearly with temperature rise.

# TEMPERATURE MEASUREMENT
# -Resistance Temperature Devices

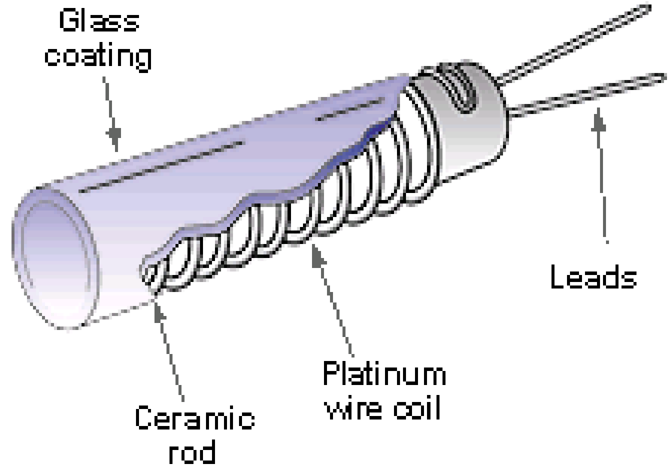
## resistance thermometer construction



# TEMPERATURE MEASUREMENT
# -Resistance Temperature Devices

- *Platinum resistance*




In the modern world, mercury and spirit-filled thermometers have largely given way to electrical devices, which can be digitised and automated. Platinum resistance thermometers are electrical thermometers which make use of the variation of resistance of high-purity platinum wire with temperature. This variation is predictable, enabling accurate measurements to be performed. They are sensitive and, with sophisticated equipment, measurements, can routinely be made to better than a thousandth part of 1 °C.

# TEMPERATURE MEASUREMENT
# -Resistance Temperature Devices

## Temperature to resistance equation

[edit]

The relation between temperature and resistance is given by the Callendar-Van Dusen equation,

$$R_T = R_0\left[1 + AT + BT^2 + cT^3(T - 100)\right]\ (-200\ ^\circ\mathrm{C} < T < 0\ ^\circ\mathrm{C}),$$
$$R_T = R_0\left[1 + AT + BT^2\right]\ (0\ ^\circ\mathrm{C} \le T < 850\ ^\circ\mathrm{C}).$$

Here, $R_T$ is the resistance at temperature $T$, $R_0$ is the resistance at 0 °C, and the constants (for an alpha=0.00385 platinum RTD) are

$$A = 3.9083 \times 10^{-3}\ ^\circ\mathrm{C}^{-1}$$
$$B = -5.775 \times 10^{-7}\ ^\circ\mathrm{C}^{-2}$$
$$C = -4.183 \times 10^{-12}\ ^\circ\mathrm{C}^{-3}.$$

Since the $B$ and $C$ coefficients are relatively small, the resistance changes almost linearly with the temperature.

# TEMPERATURE MEASUREMENT

## -the theory of thermistor

If we assume that the relationship between resistance and temperature is linear (i.e. we make a first-order approximation), then we can say that:

$$\Delta R = k\Delta T$$

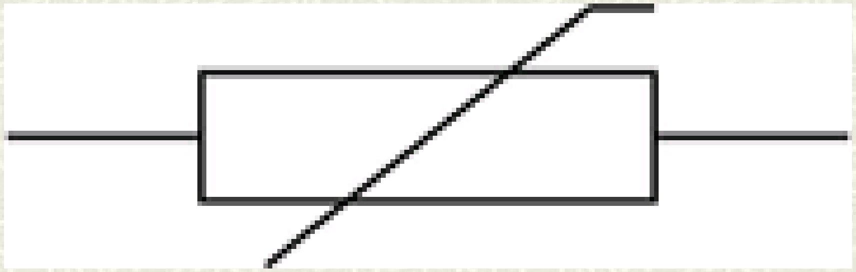
where

$\Delta R$ = change in resistance

$\Delta T$ = change in temperature

$k$ = first-order temperature coefficient of resistance

# TEMPERATURE MEASUREMENT
## -thermistor



Thermistor symbol

Thermistor, bead type, insulated wires

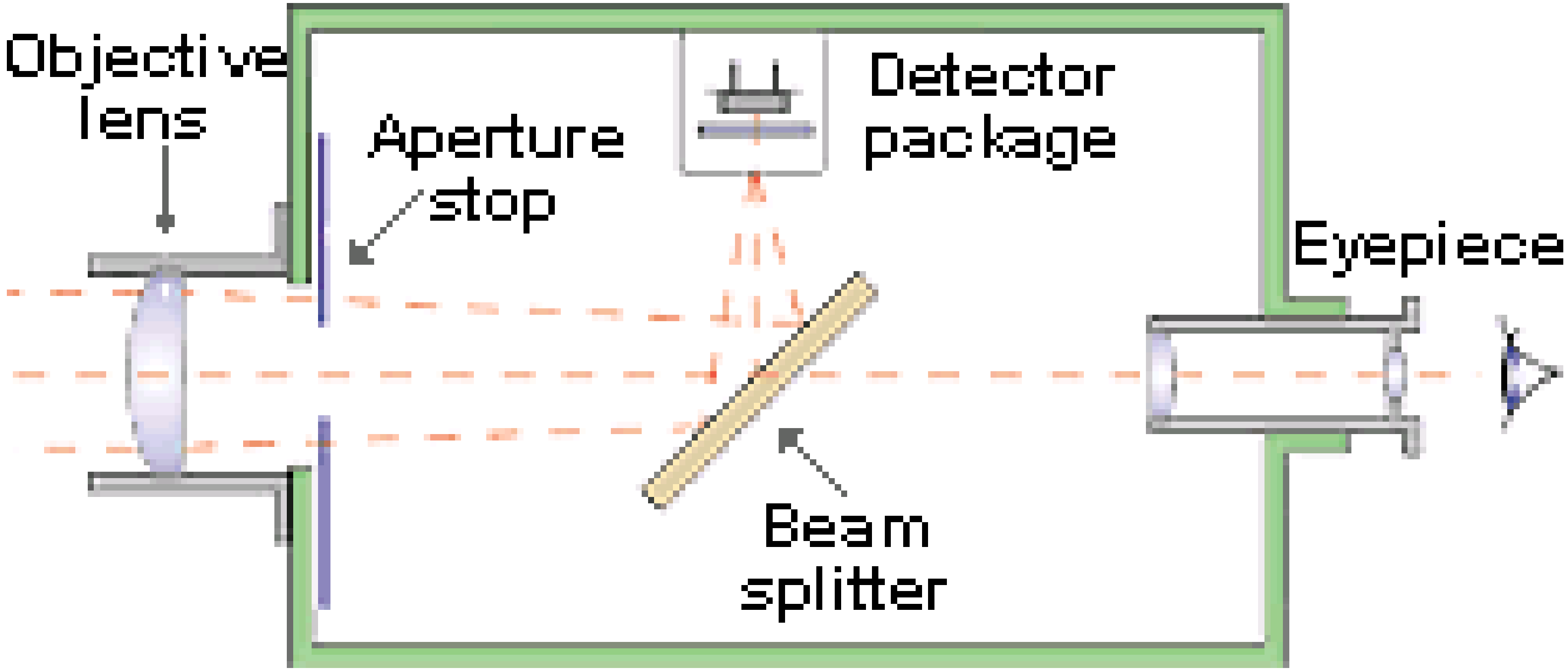
# TEMPERATURE MEASUREMENT -infrared temperature devices


Infrared sensors are noncontacting devices.

They infer temperature by measuring the thermal radiation emitted by a material.

# TEMPERATURE MEASUREMENT
## -infrared temperature devices

### Radiation pyrometer



# TEMPERATURE MEASUREMENT
## -infrared temperature devices

•Pyrometer, or radiation thermometers, make use of the fact that all objects emit thermal radiation, as seen when looking at the bars of an electric lamp or light bulb.

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

•Temperature can be measured remotely using this technique, with the sensor situated some distance away from the object.

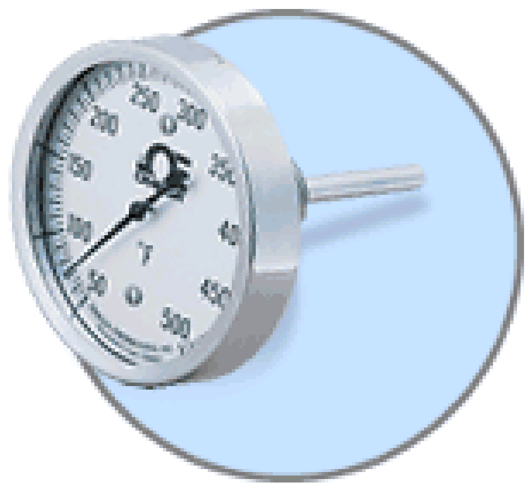
•Hence it is useful for objects that are very hot, moving or in hazardous environments.

# TEMPERATURE MEASUREMENT
## -infrared temperature devices

Inventor of pyrometer -

Pieter van Musschenbroek

# TEMPERATURE MEASUREMENT
## - bimetallic devices



AR DIALTEMP™ Bimetalic Temperature Measurement

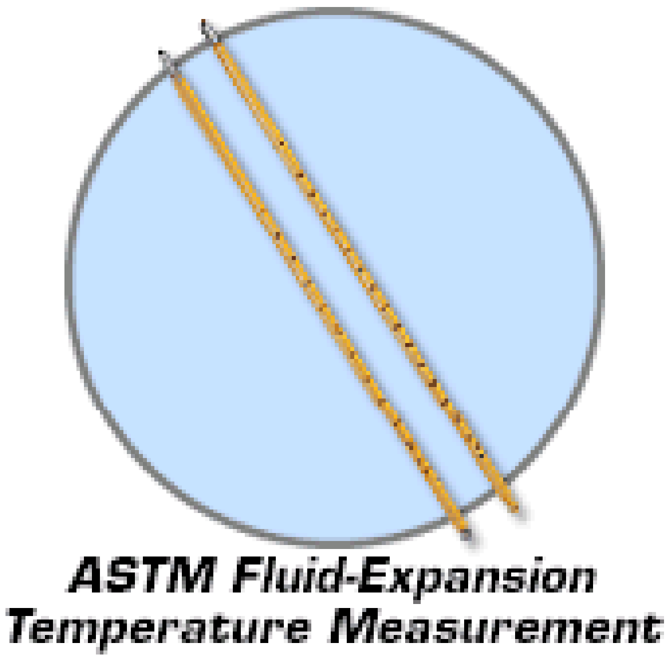
Bimetallic devices take advantage of the difference in rate of thermal expansion between different metals.

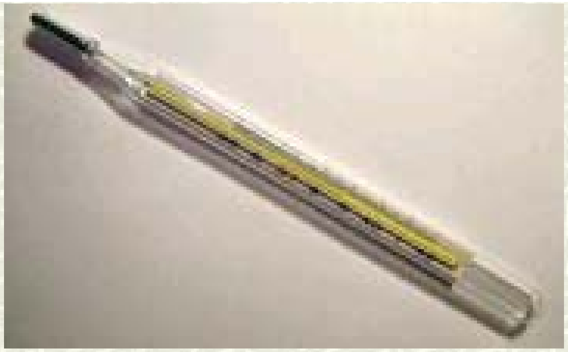
Strips of two metals are bonded together.

When heated, one side will expand more than the other, and the resulting bending is translated into a temperature reading by mechanical linkage to a pointer

# TEMPERATURE MEASUREMENT

## - fluid expansion devices



- Fluid-expansion devices, typified by the household thermometer, generally come in two main classifications:

    1. the mercury type and
    2. the organic-liquid type.

- Versions employing gas instead of liquid are also available.

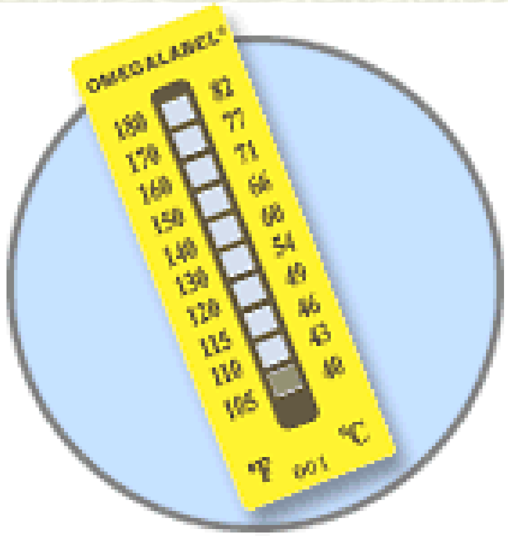
# TEMPERATURE MEASUREMENT
## - fluid expansion devices

Mercury is considered an environmental hazard, so there are regulations governing the shipment of devices that contain it.

Fluid-expansion sensors do not require electric power, do not pose explosion hazards, and are stable even after repeated cycling.

On the other hand, they do not generate data that is easily recorded or transmitted, and they cannot make spot or point measurements.

# TEMPERATURE MEASUREMENT
## - change-of-state devices




**TL-10 Change-of-State Temperature Measurement**

Change-of-state temperature sensors consist of labels, pellets, crayons, lacquers or liquid crystals whose appearance changes once a certain temperature is reached.

They are used, for instance, with steam traps - when a trap exceeds a certain temperature, a white dot on a sensor label attached to the trap will turn black.

# TEMPERATURE MEASUREMENT
## - change-of-state devices

**Response time** typically **slow**, so these devices often do not respond to transient temperature changes.

And **accuracy is lower** than with other types of sensors.

Furthermore, the **change in state is irreversible**, except in the case of liquid-crystal displays.

Even so, change-of-state sensors can be **handy** when one needs confirmation that the temperature of a piece of equipment or a material has not exceeded a certain level, for instance for technical or legal reasons during product shipment.

# THE END