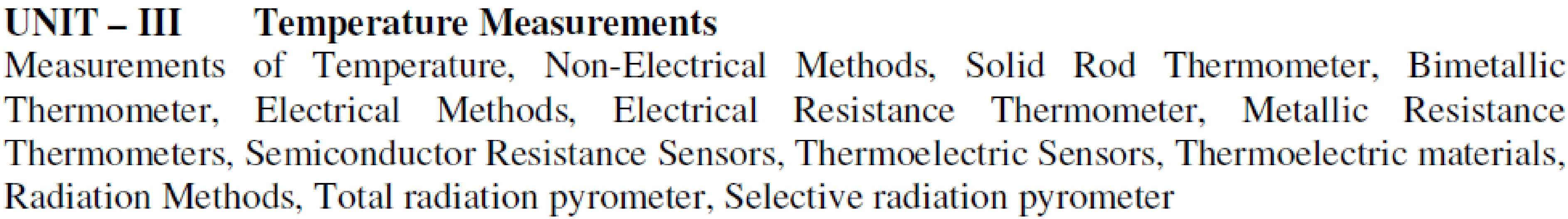
UNIT 3

Part 1

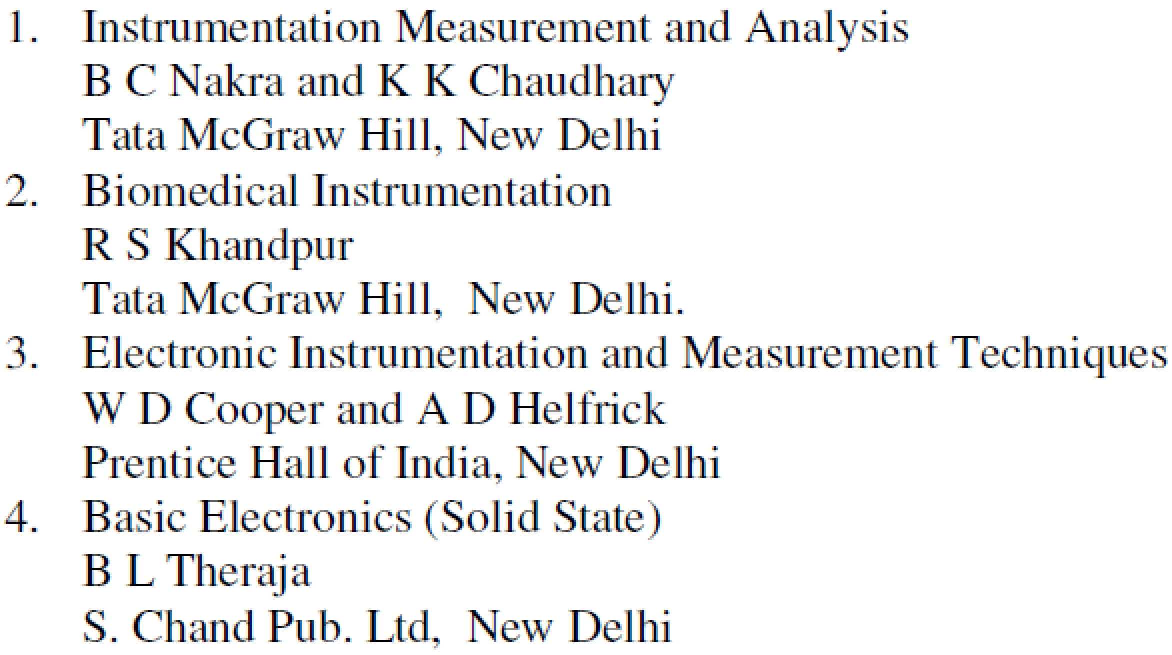
“Temperature Measurements”

US06CPHY06
Instrumentation and Sensors



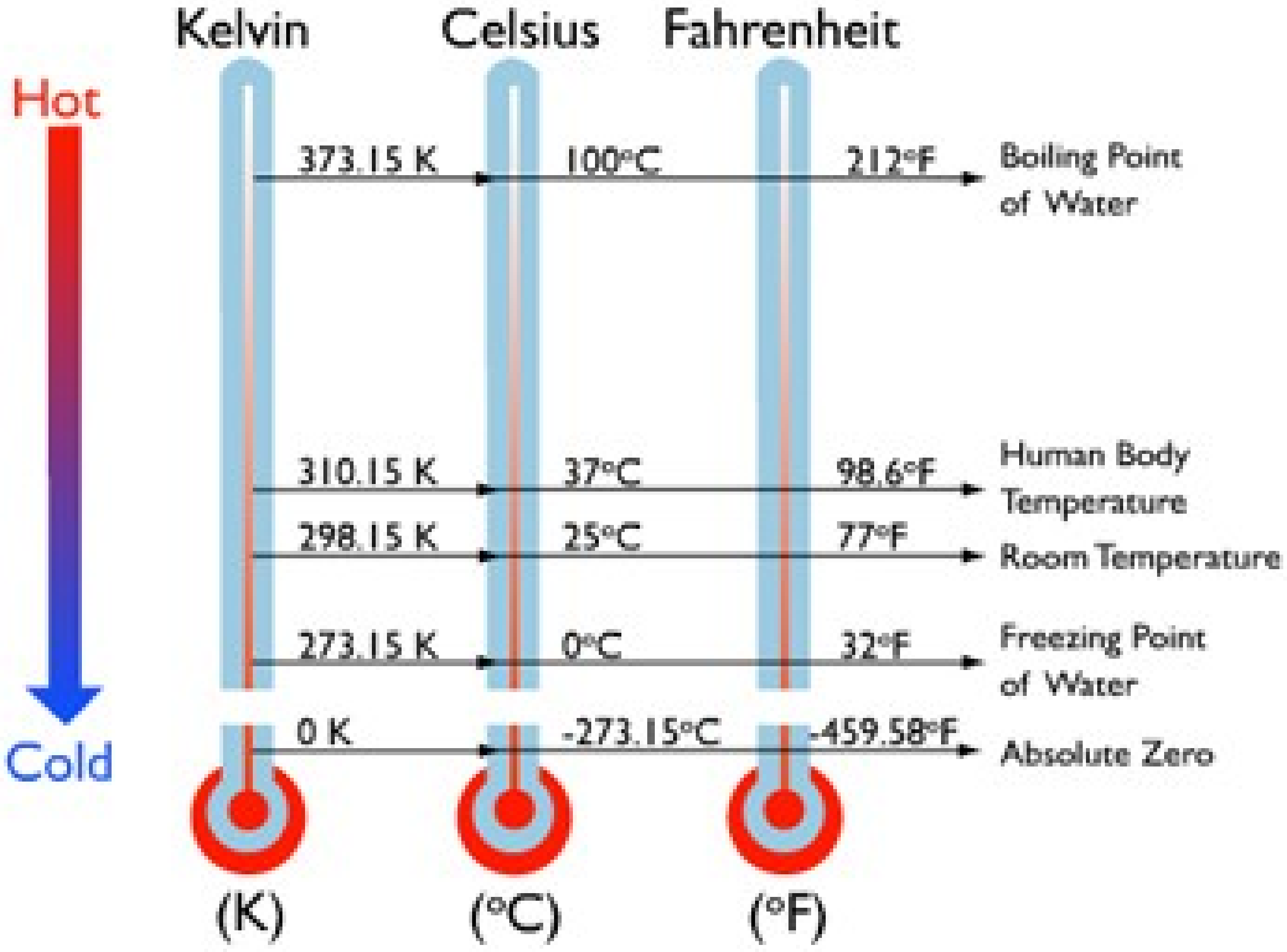
UNIT – III Temperature Measurements

Measurements of Temperature, Non-Electrical Methods, Solid Rod Thermometer, Bimetallic Thermometer, Electrical Methods, Electrical Resistance Thermometer, Metallic Resistance Thermometers, Semiconductor Resistance Sensors, Thermoelectric Sensors, Thermoelectric materials, Radiation Methods, Total radiation pyrometer, Selective radiation pyrometer

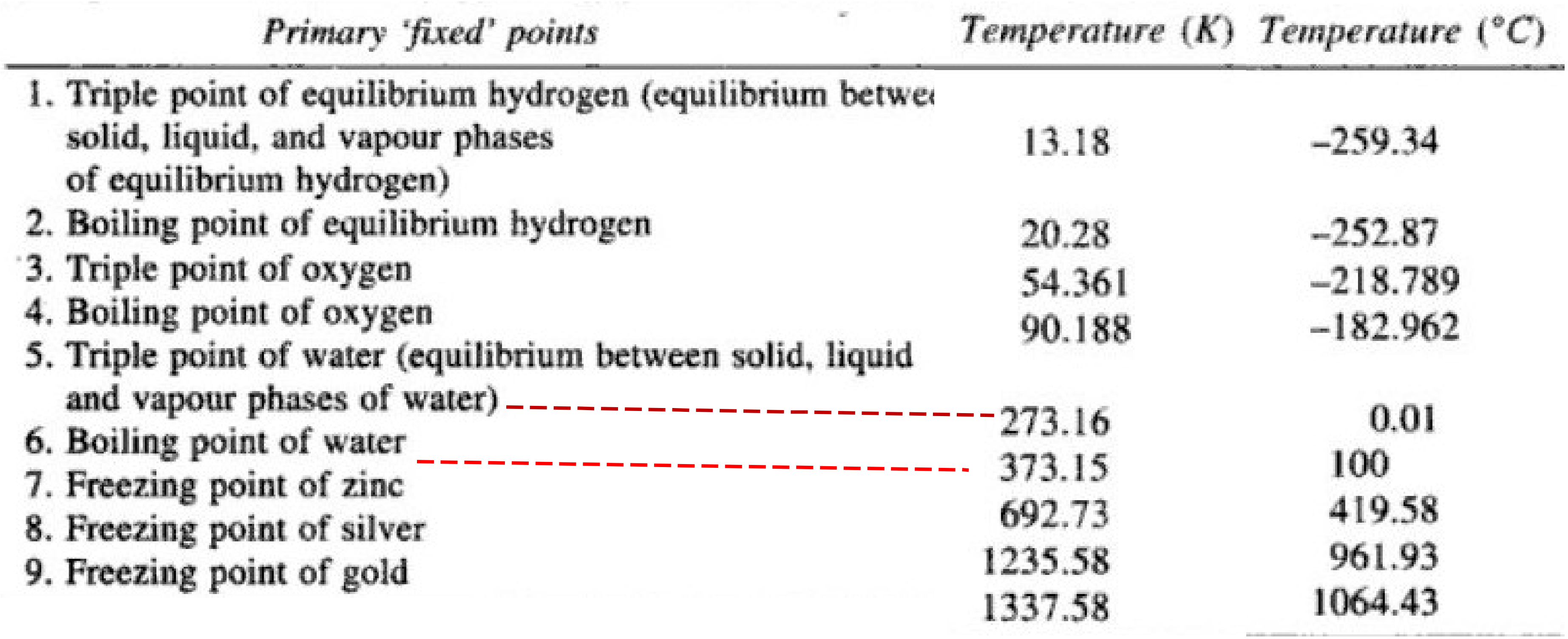


1. Instrumentation Measurement and Analysis
   B C Nakra and K K Chaudhary
   Tata McGraw Hill, New Delhi
2. Biomedical Instrumentation
   R S Khandpur
   Tata McGraw Hill, New Delhi.
3. Electronic Instrumentation and Measurement Techniques
   W D Cooper and A D Helfrick
   Prentice Hall of India, New Delhi
4. Basic Electronics (Solid State)
   B L Theraja
   S. Chand Pub. Ltd, New Delhi

Temperature Scales



Temperature Scales



Primary 'fixed' points	*Temperature (K)*	*Temperature (°C)*
1. Triple point of equilibrium hydrogen (equilibrium betwe solid, liquid, and vapour phases of equilibrium hydrogen)	13.18	–259.34
2. Boiling point of equilibrium hydrogen	20.28	–252.87
3. Triple point of oxygen	54.361	–218.789
4. Boiling point of oxygen	90.188	–182.962
5. Triple point of water (equilibrium between solid, liquid and vapour phases of water)	273.16	0.01
6. Boiling point of water	373.15	100
7. Freezing point of zinc	692.73	419.58
8. Freezing point of silver	1235.58	961.93
9. Freezing point of gold	1337.58	1064.43

Temperature Measurement Methods

- Non Electrical
- Electrical
- Radiation

Non Electrical Methods: *Solid Rod Thermometer*

Principle: Metal expansion due to heat

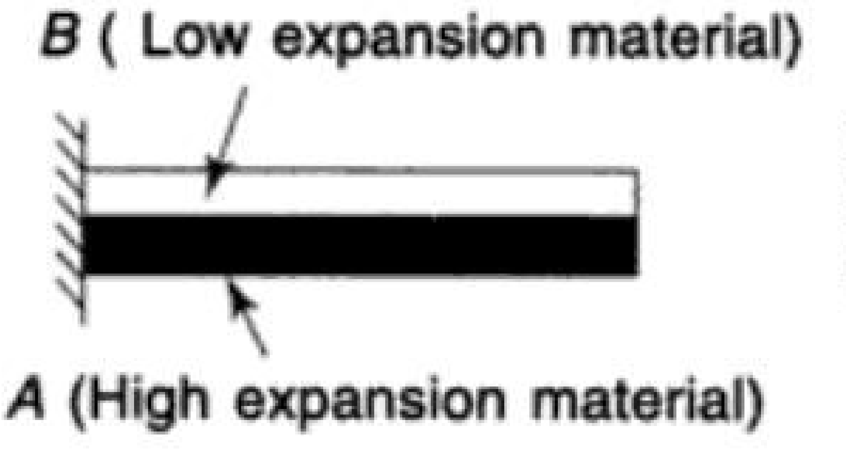
l: change in length *α : expansion coefficient* *l_0: original length*

Metal Expansion: $l = l_o \alpha \Delta T$

- Simple in construction & inexpensive
- Slow response due to large metal mass
- Solid rod thermostat as a microswitch domestic water heater or owen.

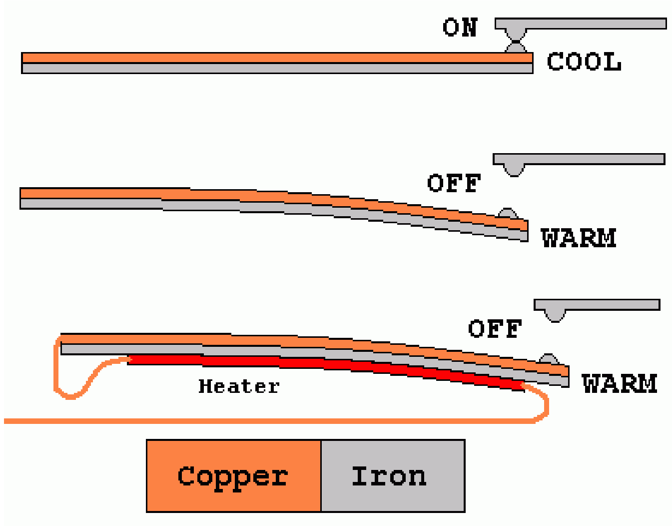
Non Electrical Methods: Bimetallic Strip

Principle: Metal expansion due to heat



Cold

- Deflection is nearly linear depending on α.
- Invar (Fe:Ni alloy, with 36% Ni) :
- Invar with low α ~ (1/20)th of normal metal.
- Brass is with higher α.
- To increase sensitivity, used in helical form.



Bimetallic Strip: Helix

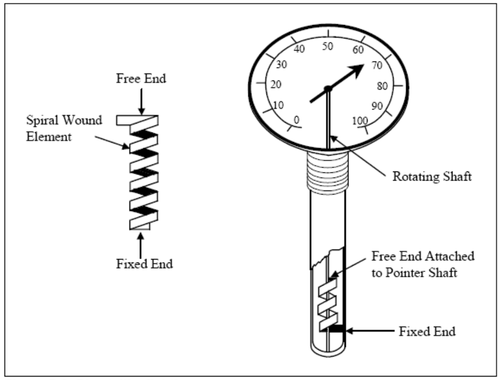


Figure 7-3. Bimetallic dial thermometer

- **Operating range: -30 to 550 ^{0}C. Inaccuracies ~ 0.5 to 1% of FSD**
- **Control & Sensing systems. (ON/OFF) e.g.**

  Domestic owen, Electric irons, Car winker lamps.

2. Electrical Methods:

Advantage:

More convenient : electrical signal ,easily detected, amplified, displayed, stored and communicated.

Types:

- Variable Controlled Parameter Transducers
  i.e. variable resistance transducers or
  electrical resistance thermometers

- Self Generating Transducers
  i.e. thermo-electric transducers

Electrical Resistance Thermometers

Principle: Change in resistance with temperature

Semiconductor
Resistance Sensors
“Thermistors”

Metallic
Resistance
Thermometers

Metallic Resistance Thermometers

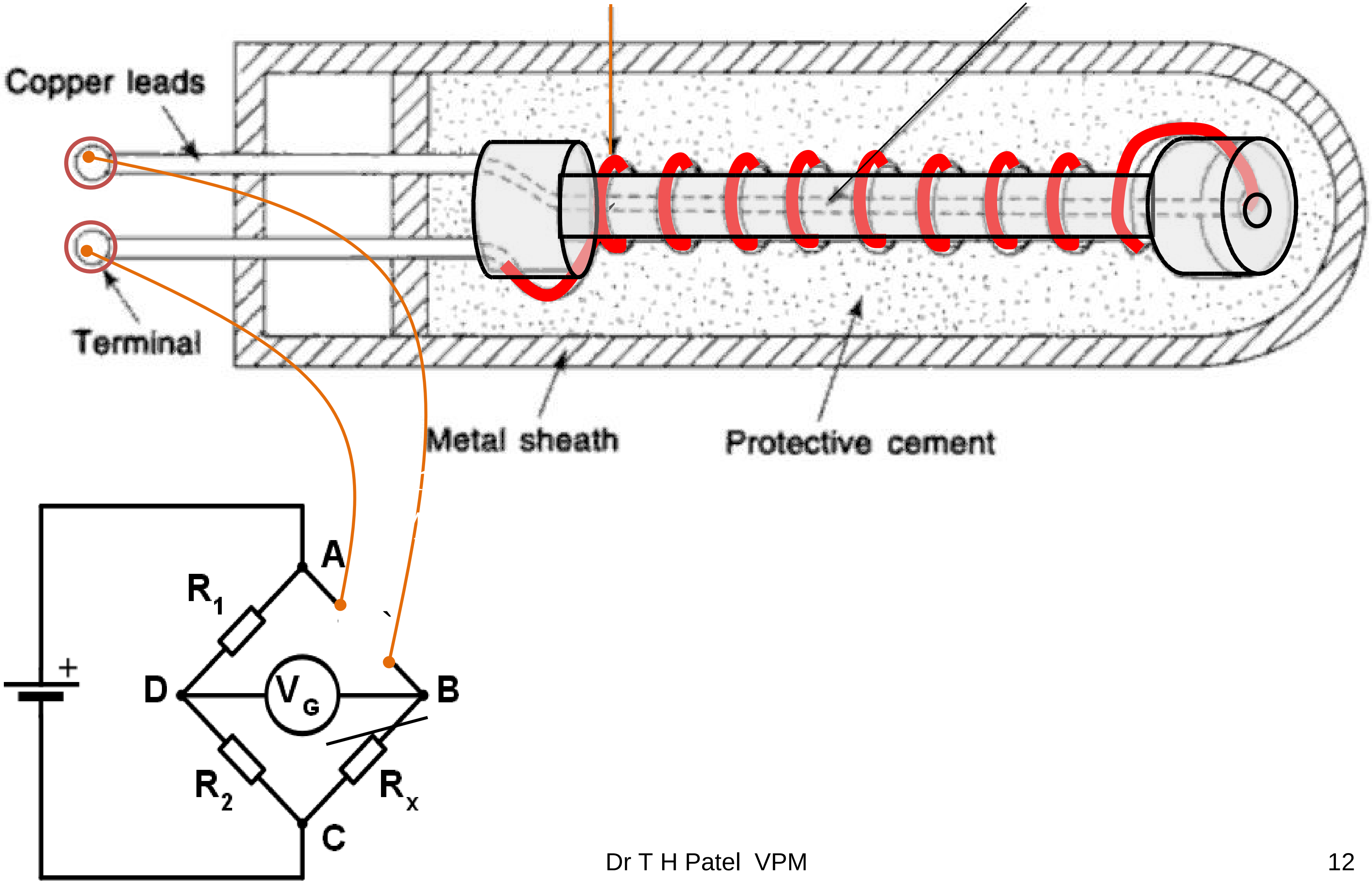
- Metals like Pt, Cu, W and Ni exhibit PTC.
- For lower temperature upto 600 ^{0}C, *MRTs* are more suitable for both laboratory and industrial applications due to their;

  High degree of Accuracy and

  Long term Stability.

Metallic Resistance Thermometers

Pt or Cu or Ni
Resistance element coil



Metallic Resistance Thermometers

Features:

- Platinum has low sensitivity and high cost compared to Ni & Cu. ***Although more used.***
- Temp.- Resi. Characteristics of pure Pt are *well defined and more stable over wide temp*. range.
- Pt has high resistance to chemical attacks & contaminations ensuring *long term stability*.
- Easily reproducible type of temperature transducer with a *high degree of accuracy*.

Metallic Resistance Thermometers

The resistance–temperature relationship for most of the metals is :

$$R = R_0[1 + aT + bT^2]$$

where, ***R*** = resistance at absolute temperature ***T***,

R₀= resistance at temperature 0 ^{0}C and

a & ***b*** are experimetally determined constants.

However, for limited temperature range around 0 ^{0}C the linear relationship can be applied as:

$$R_t = R_0(1 + \alpha t)$$

where ***α*** = temperature coefficient of resistance of material in (Ω/Ω)/^{0}C or ^{0}C^{-1} and

R_t = resistance at temperature t relative to 0 ^{o}C.

Metallic Resistance Thermometers

The values of α for;

Copper: 0.0043 $^0C^{-1}$

Platinum: 0.0039 $^0C^{-1}$

Nickel: 0.0068 $^0C^{-1}$

For a change in temperature from t_1 to t_2 , the relation;

$$R_t = R_0(1 + \alpha t)$$

can be written as

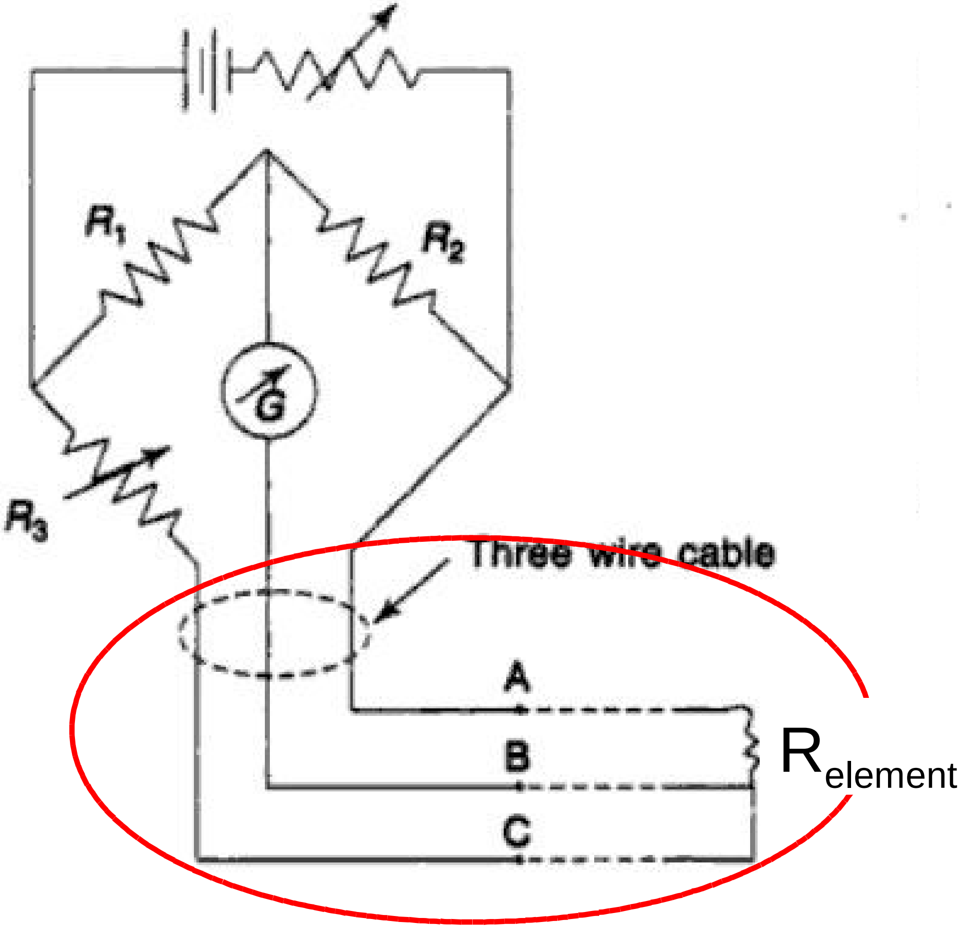
$$R_2 = R_1 + R_0\alpha(t_2 - t_1)$$

$$t_2 - t_1 = \frac{R_2 - R_1}{\alpha R_0}$$

$$t_2 = t_1 + \frac{R_2 - R_1}{\alpha R_0}$$

Metallic Resistance Thermometers

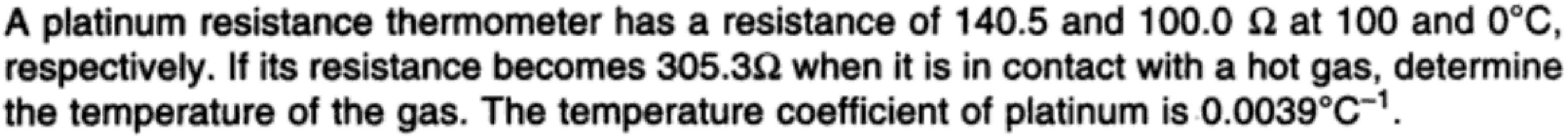
Lead (Cable) compensation methods



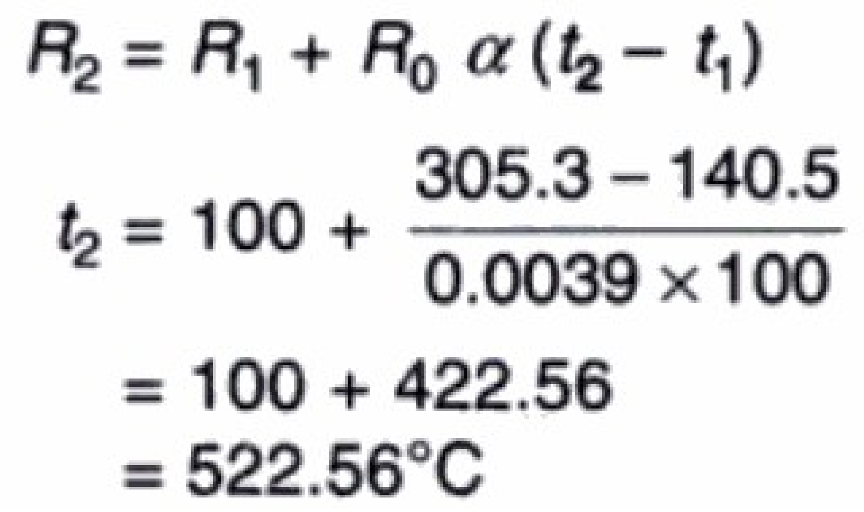
Siemens's three wire lead arrangement

Calendar's four wire lead arrangement

Metallic Resistance Thermometers



A platinum resistance thermometer has a resistance of 140.5 and 100.0 Ω at 100 and 0°C, respectively. If its resistance becomes 305.3Ω when it is in contact with a hot gas, determine the temperature of the gas. The temperature coefficient of platinum is $0.0039°\text{C}^{-1}$.



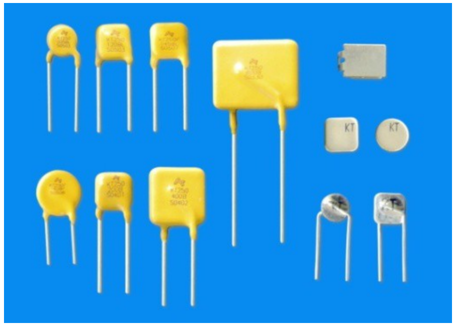
$$R_2 = R_1 + R_0\,\alpha\,(t_2 - t_1)$$

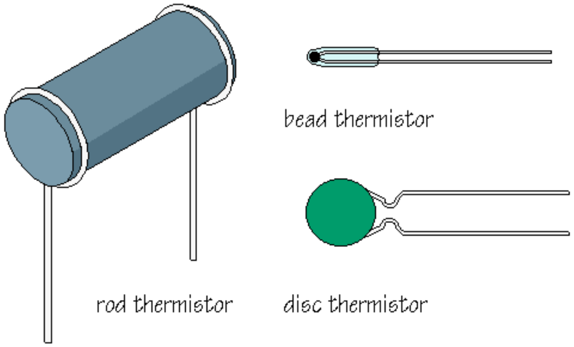
$$t_2 = 100 + \frac{305.3 - 140.5}{0.0039 \times 100}$$

$$= 100 + 422.56$$

$$= 522.56°\text{C}$$

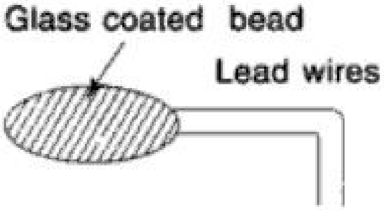
Semiconductor Resistance Sensors: Thermistors



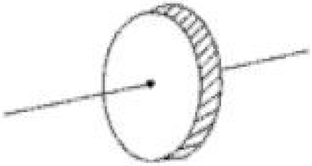


- Thermally sensitive variable resistors
- Made from ceramic like semiconductor materials.
- Cold resistance ranging from few Ω to MΩ.
- Respond negatively to temperature.
- 10 times higher coefficient of resistance than Pt/Cu.
- Made up from oxides of Cu, Mn,Ni,Co and Li.
- Oxides- mixed in various proportion- powdered-compressed-shaped-heated to recrystallize-final dense ceramic body with desired R-T characteristics.

Various types of thermistors:

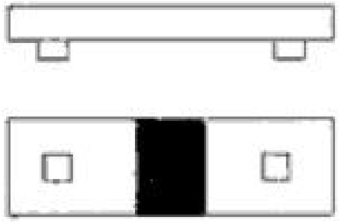


(a) Bead (Typical diameter 1 mm)

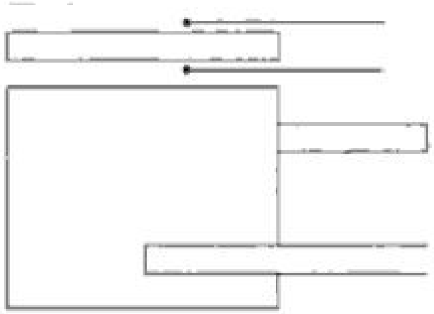


(b) Disc (Typical thickness 1 mm)

(c) Rod (Typical diameter 1 mm)



(d) I.C. Chip (Typical dimension 1.25 mm × 100 mm 0.3 mm thickness)



(e) Wafer (Typical dimension 1.25 mm to 15 mm × 0.3 mm thickness)

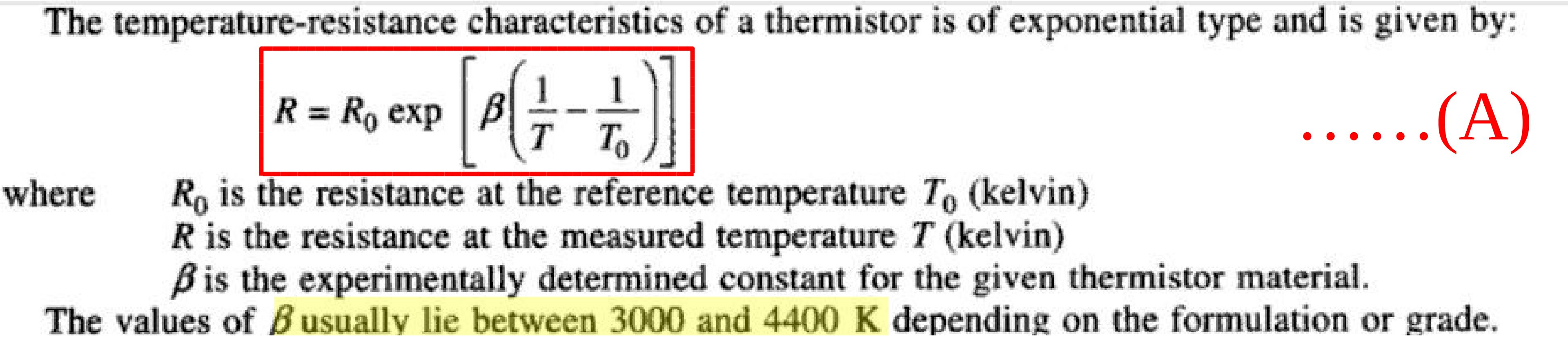
Advantages of thermistors:

- Large Temp. Coeff. - High Sensitivity - +_ 0.01 ^{o}C Accuracy
- Withstand ele. & mech. Stress
- Good Operating range: -100 to 300^{o}C
- Low cost
- Small Size – fast thermal response
- Easy adoptability with bridges
- Useful for dynamic measurements

Disadvantages of thermistors:

- Highly non-linear R-T Characteristics
- Self-heating effects
- much lower currents are required to operate

R-T relation for thermistors:



The temperature-resistance characteristics of a thermistor is of exponential type and is given by:

$$\boxed{R = R_0 \exp\left[\beta\left(\frac{1}{T} - \frac{1}{T_0}\right)\right]} \qquad \text{......(A)}$$

where R_0 is the resistance at the reference temperature T_0 (kelvin)
R is the resistance at the measured temperature T (kelvin)
β is the experimentally determined constant for the given thermistor material.

The values of β usually lie between 3000 and 4400 K depending on the formulation or grade.

Thermistors:

For a certain thermistor, $\beta = 3140$ K and the resistance at 27°C is known to be 1050 Ω. The thermistor is used for temperature measurement and the resistance measured is as 2330 Ω. Find the measured temperature.

The governing equation of the temperature-resistance characteristics of the thermistor is given by:

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

The given data is:

$$R_0 = 1050\ \Omega$$
$$T_0 = 273 + 27 = 300\ \text{K}$$
$$\beta = 3140\ \text{K}$$
$$R = 2330\ \Omega$$

Taking the logarithm of both sides of equation and rearranging we get,

$$\frac{1}{T} = \frac{\ln R - \ln R_0}{\beta} + \frac{1}{T_0}$$

$$= \frac{7.754 - 6.957}{3140} + \frac{1}{300}$$

$$= 3.587 \times 10^{-3}$$

US06CPHY06

Instrumentation and Sensors

Radiation Methods

(Pyrometry)

Radiation Methods: (Pyrometry)

Features:

- No direct contact of the object.
- Convenient when object is moving.
- Surface can be scanned for temp. gradient.

- The objects with T > 650 °C emits heat radiation with sufficient intensity which can be measured for temperature determination.
- Instruments working in thin manner are called as pyrometers.

Pyrometers

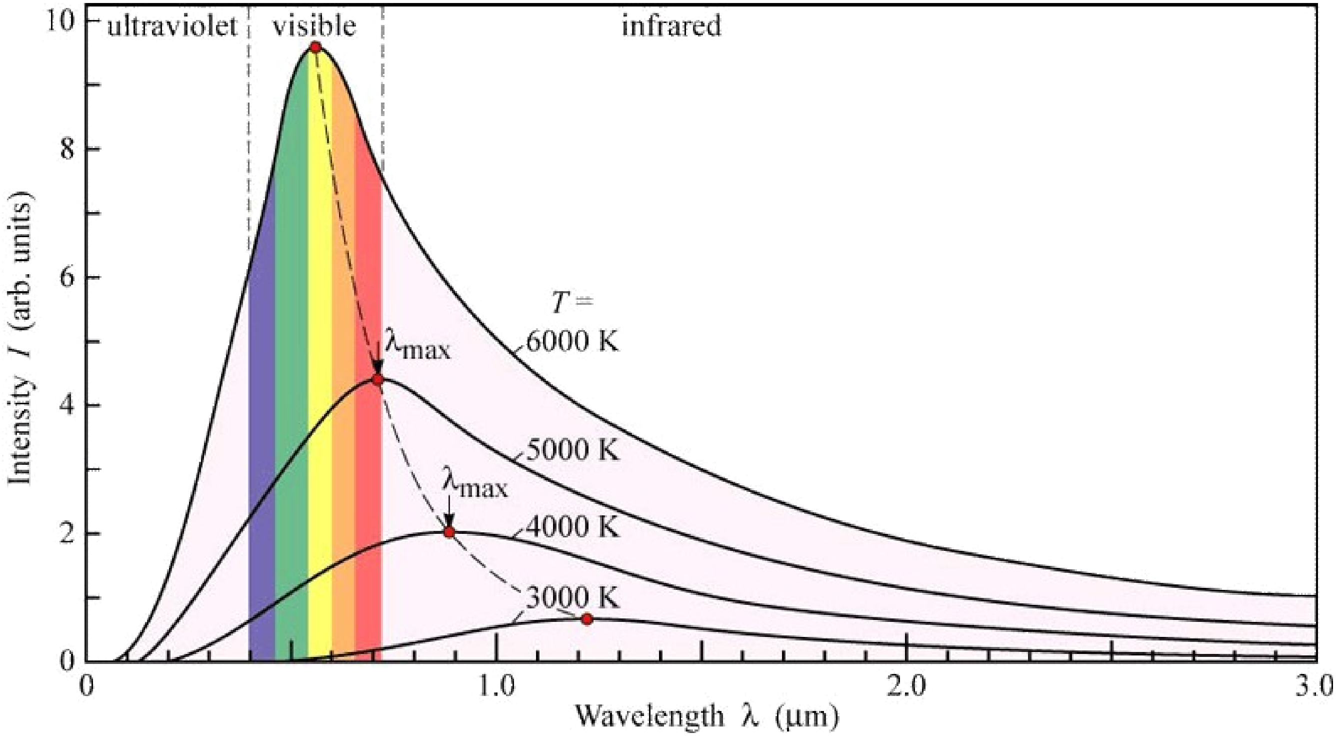
- Total radiation Pyrometers:
  Sensitive to all radiation that enters the instrument.

- Selective (partial) radiation Pyrometers:
  Sensitive only to a particular radiation that enters the instrument.

Total Radiation Pyrometer

First Designed by: **Fery**

Aim: Measurements of total energy of all incident wavelengths



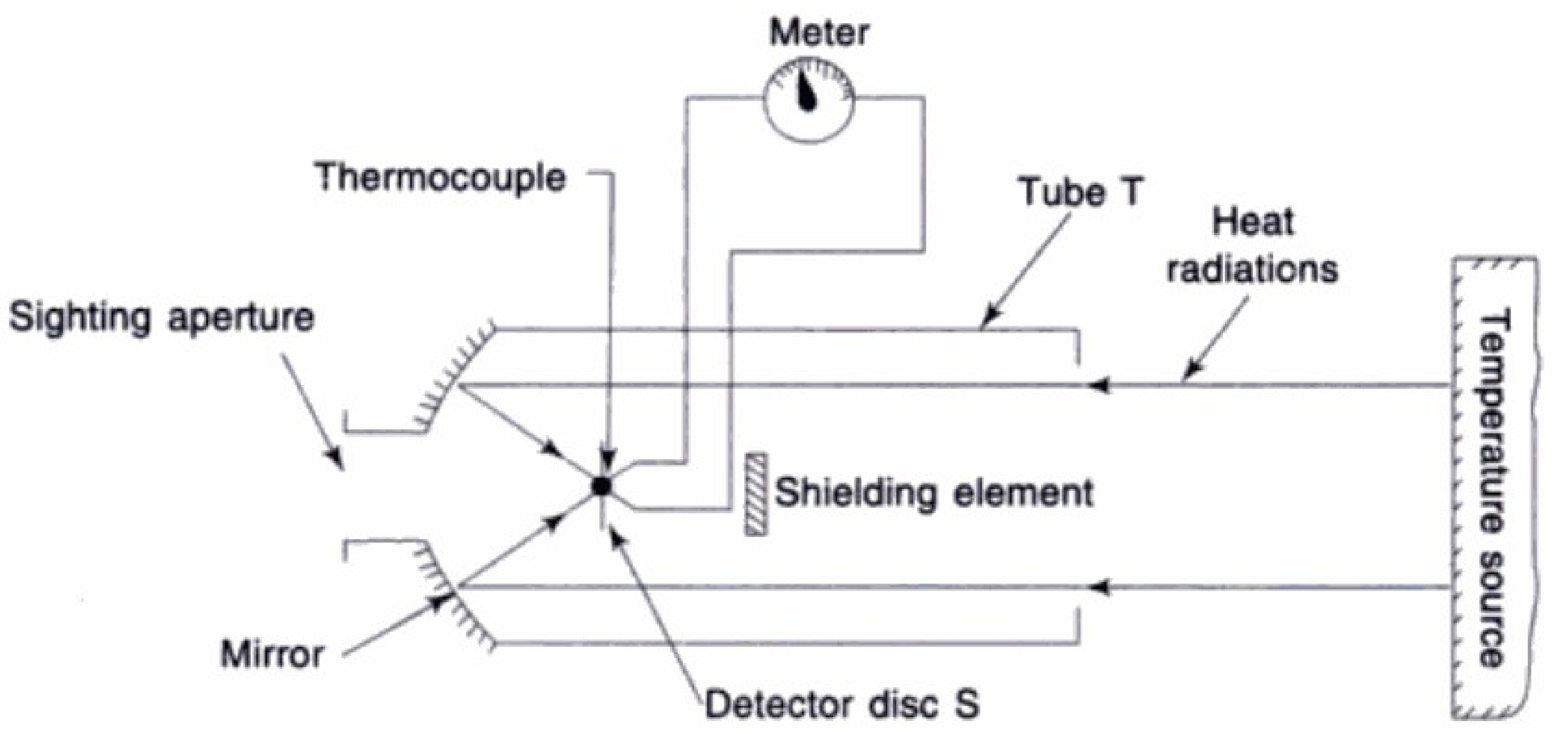
Total Radiation Pyrometer

Characteristic Features

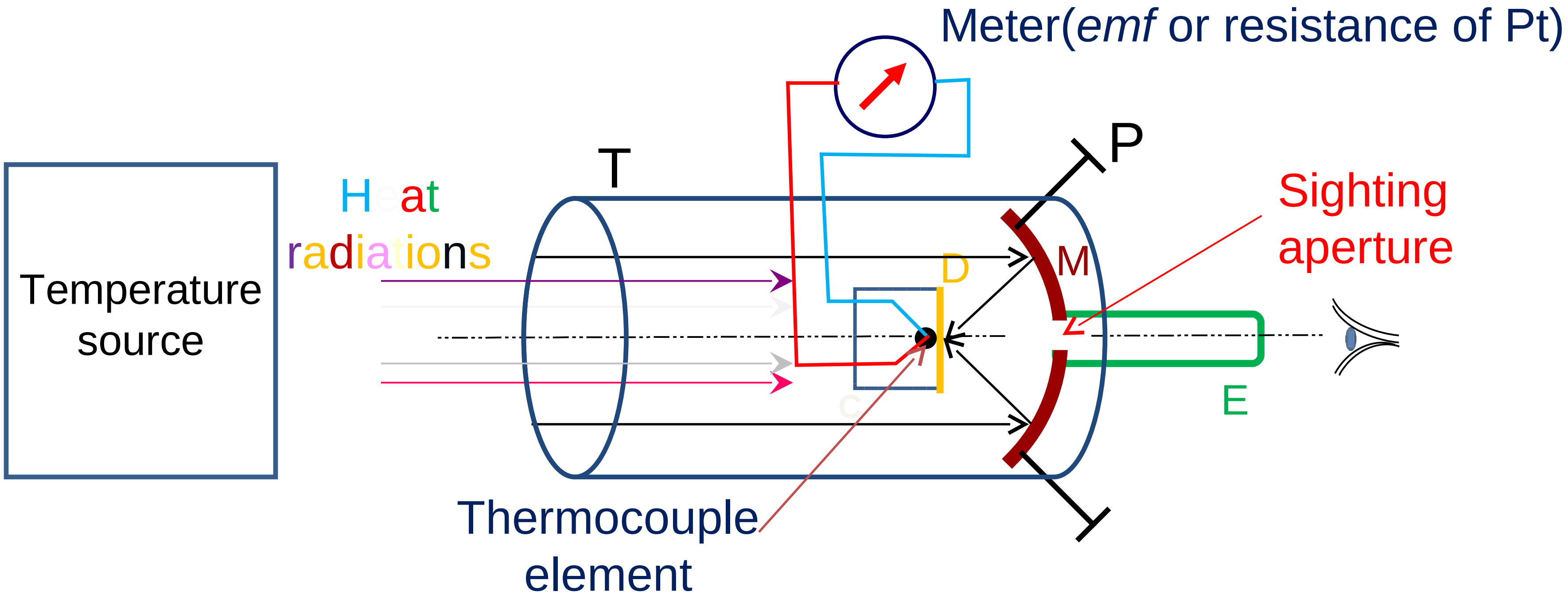
- Sample of the total radiation focused on to a temp. sensor.
- Total radiation = visible (light 0.3 to 0.72 μm) +
  invisible (infrared 0.72 to 1000 μm)
- IR -larger λs -require special opt. materials for focusing.
- Ordinary glass is unsatisfactory as it absorbs infrared radiations.
- Practical radiation pyrometers are sensitive to a limited wavelength band (0.32 to 0.4 μm) of radiant energy whereas theory predicts sensitivity for entire spectrum of radiation emitted.

Total Radiation Pyrometer:Construction

First Designed by: **Fery**



Total Radiation Pyrometer : Construction



Meter(*emf* or resistance of Pt)

Temperature source

Heat radiations

Sighting aperture

Thermocouple element

Total Radiation Pyrometer: Working Principle

- The rate of radiation from a body A (Source) to a body B (pyrometer),

$E_{A/B}$ is given by Stefan-Boltzmann Law as:

$$E_{A/B} = C\,\varepsilon\,\sigma\,(T_A^4 - T_B^4)$$

where,

C = geometrical factor to adjust relative shapes of bodies A and B

ε = emissivity of detector disc (~ 0.05 to1 for theoretical blackbody),

σ = Stefan-Boltzmann $= 56.7 \times 10^{-12}$ kW/(m^2 K^4)

T_A and T_B are steady state absolute temperatures of the source and the detector disc respectively.

Total Radiation Pyrometer: Features

- They are calibrated in terms of temp. : 700-2000 ^{0}C

  (where Thermocouples and ResistanceThermometrs can not be employed)

- Errors arises due to:

1. Filtering materials (smoke, dust, gases, windows, etc.) which were not present while calibrating reduces energy received.
2. Change in surface emissivity(oxidation of surface with time or use of surface other than that used on calibration.)

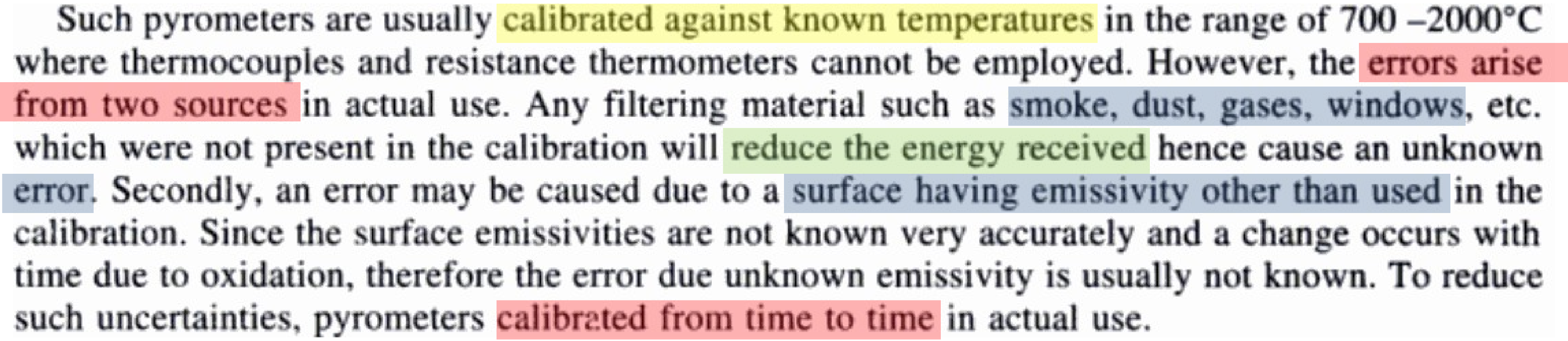
Hence they need to calibrate from time-to-time in practical use.

- Due to these reasons they are *not very accurate temp. indicators.*

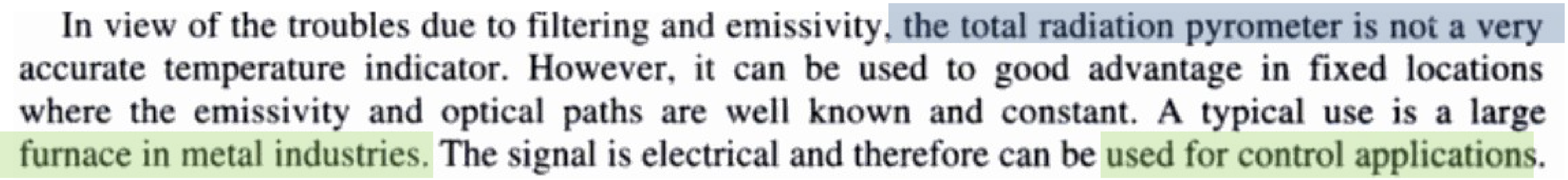
- *However good at fixed locations where emissivity and optical paths are well known and constant such as large furnace in a metal industries.*

The output electrical signal can be used for control applications.

Total Radiation Pyrometer

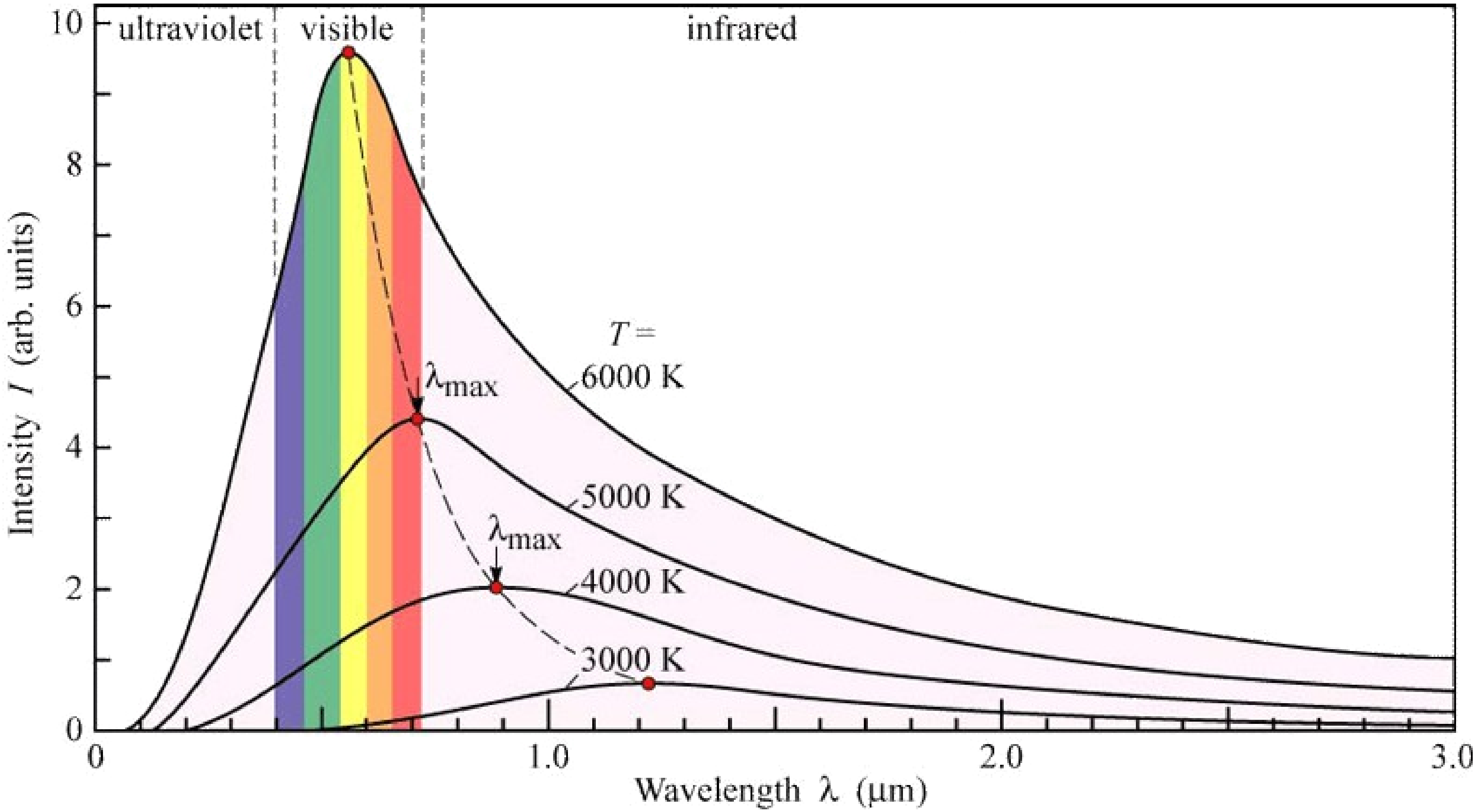


Such pyrometers are usually calibrated against known temperatures in the range of 700 –2000°C where thermocouples and resistance thermometers cannot be employed. However, the errors arise from two sources in actual use. Any filtering material such as smoke, dust, gases, windows, etc. which were not present in the calibration will reduce the energy received hence cause an unknown error. Secondly, an error may be caused due to a surface having emissivity other than used in the calibration. Since the surface emissivities are not known very accurately and a change occurs with time due to oxidation, therefore the error due unknown emissivity is usually not known. To reduce such uncertainties, pyrometers calibrated from time to time in actual use.



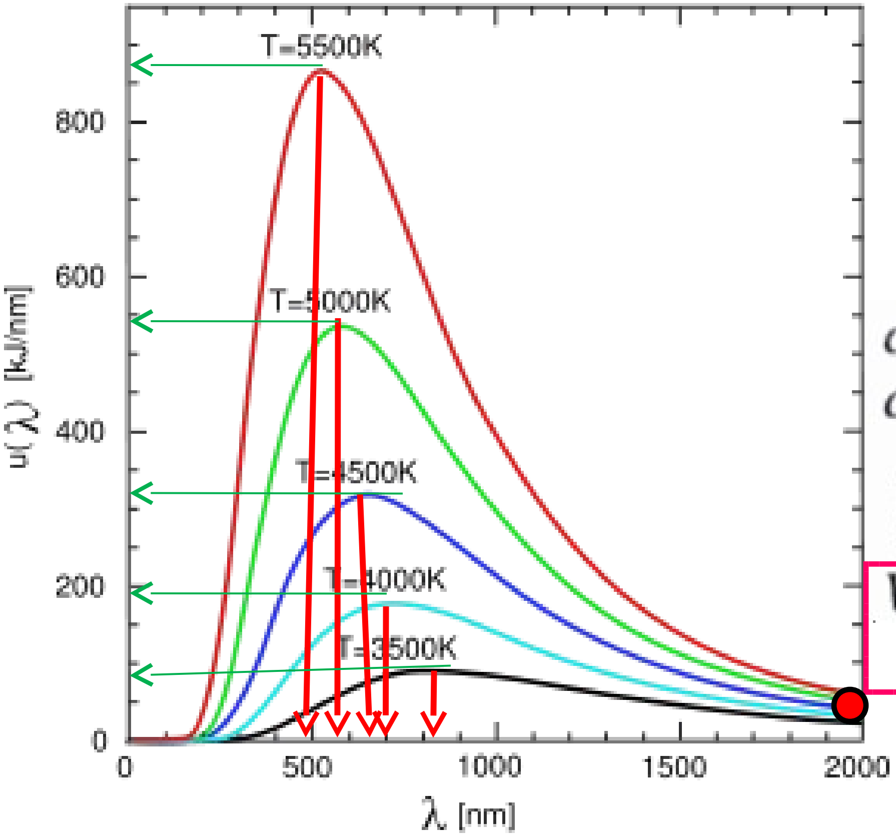
In view of the troubles due to filtering and emissivity, the total radiation pyrometer is not a very accurate temperature indicator. However, it can be used to good advantage in fixed locations where the emissivity and optical paths are well known and constant. A typical use is a large furnace in metal industries. The signal is electrical and therefore can be used for control applications.

Selective Radiation Pyrometer



- Principle: Planck law of radiation
- Energy levels in a radiation from a hot body are distributed in different λ’s.
- As T increases, emissive power shifts to shorter λ .

Selective Radiation Pyrometer



Planck law of heat distribution:

$$W = \frac{c_1 \lambda^{-5}}{e^{c_2 \backslash \lambda T} - 1}$$

$c_1 = 3.740 \times 10^{-12}$ (W–cm^2)

$c_2 = 1.4385$ (cm –°C)

λ = wavelength (cm)

T = absolute temperature in (K)

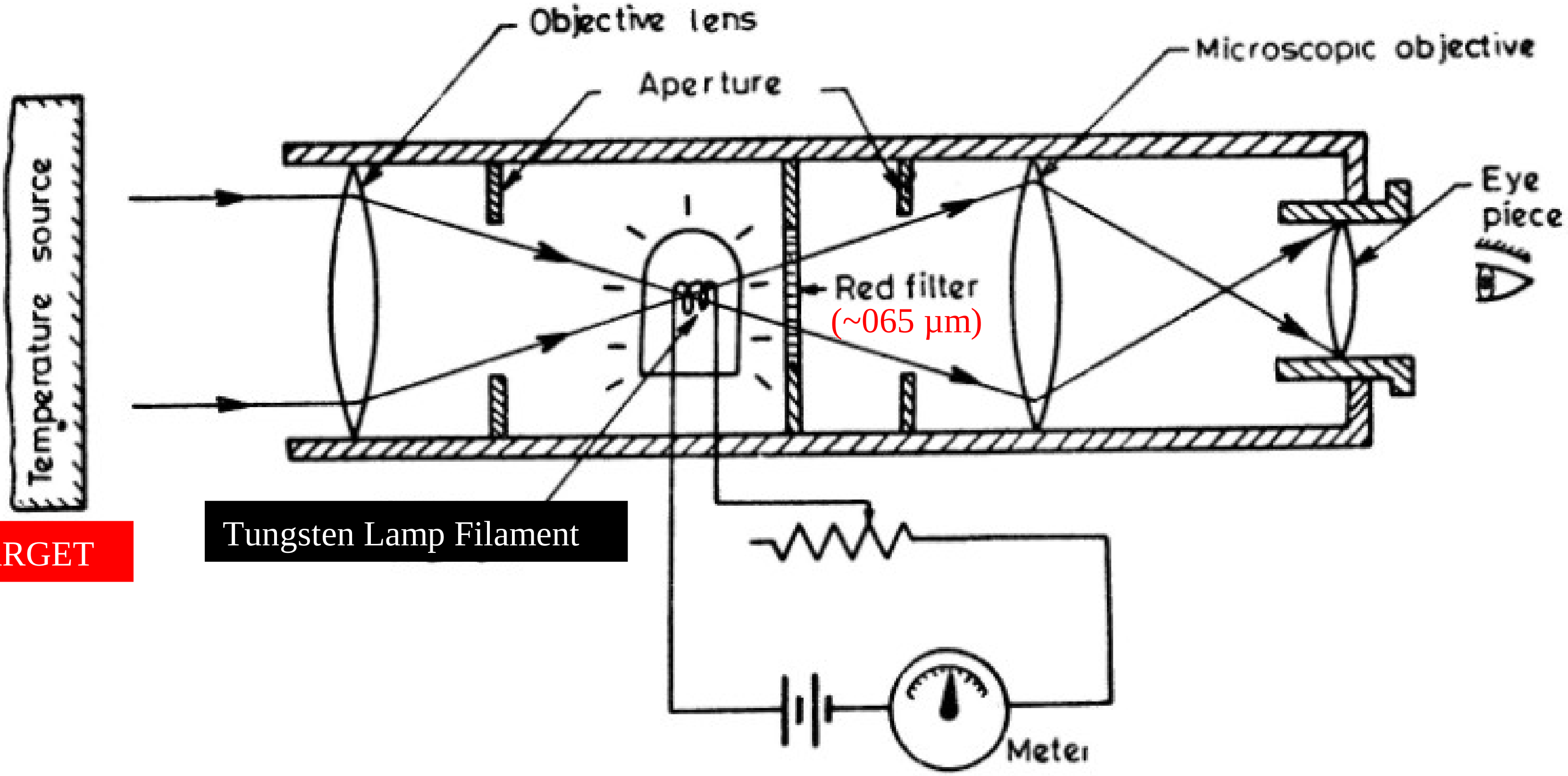
W = energy level associated with wavelength at temperature T (W/cm^3)

- Principle: Planck law of heat distribution.
- Energy levels in a radiation from a hot body are distributed in different λ’s.
- As T increases, emissive power shifts to shorter λ .

Disappearing Filament / Optical Pyrometer

Designed by: Holborn, Kurlbaum and Henning

Aim: Measurements of unknown temperature

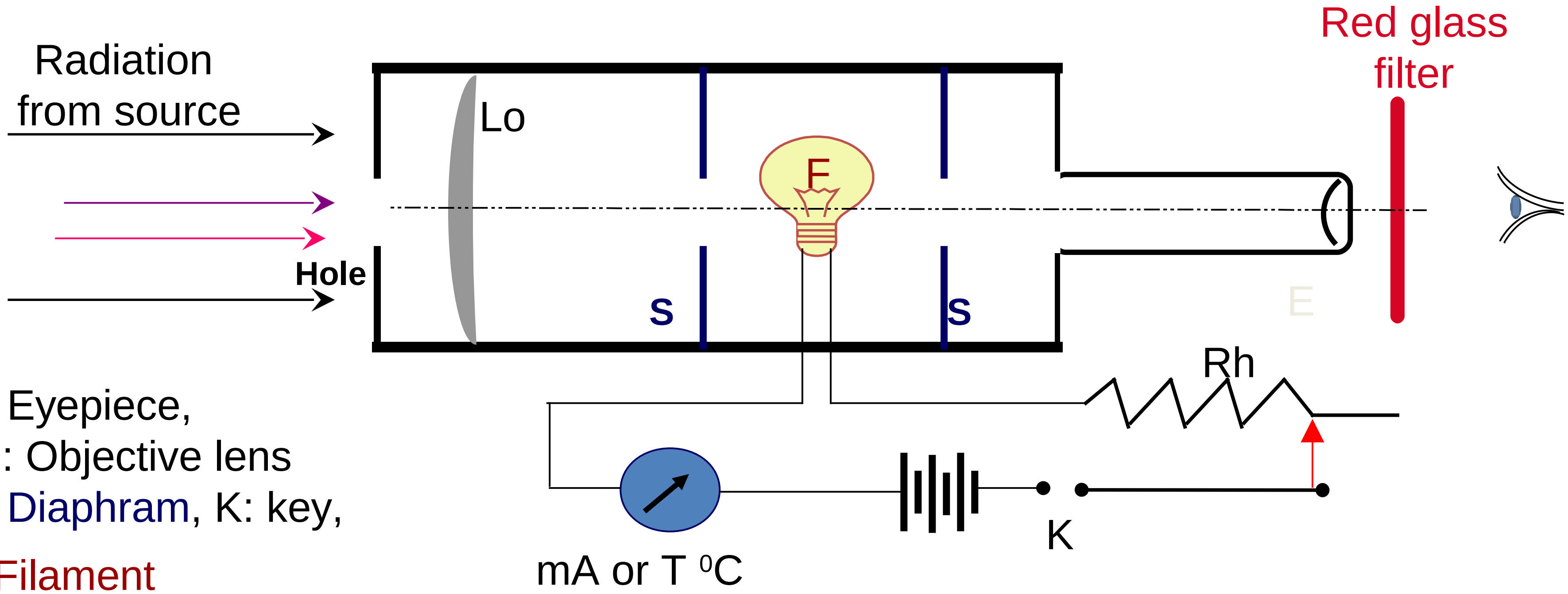


TARGET

Tungsten Lamp Filament

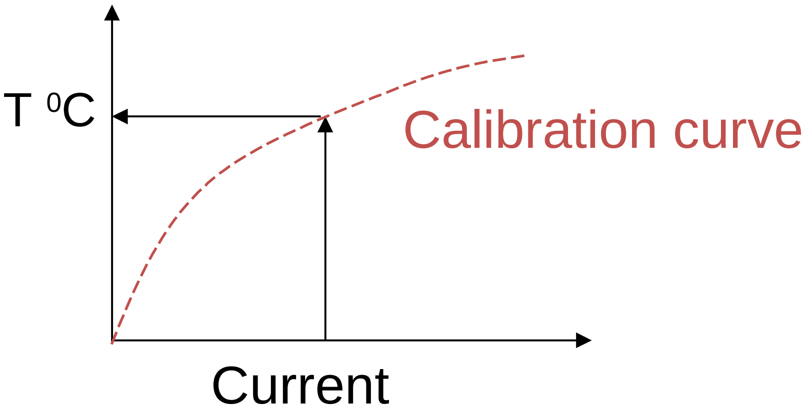
(~065 µm)

Disappearing Filament Pyrometer



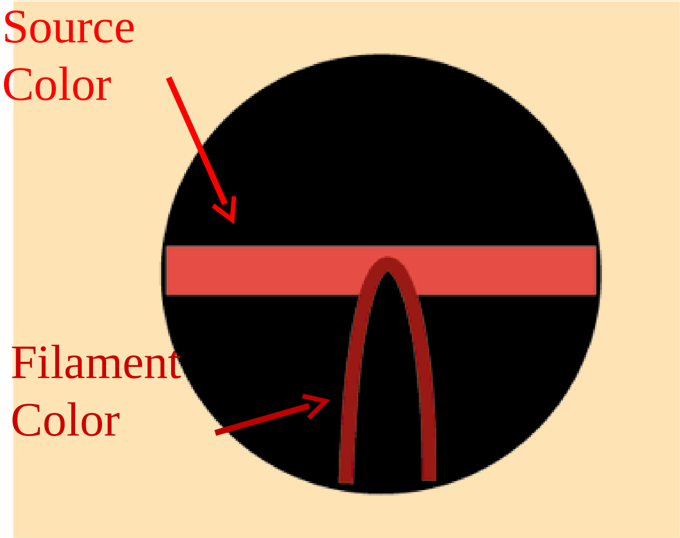
E: Eyepiece,
Lo: Objective lens
S: Diaphram, K: key,

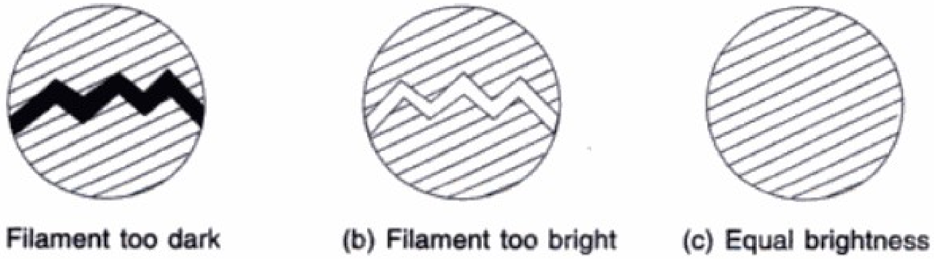
F:Filament
Rh: Rheostate



Disappearing Filament / Optical Pyrometer

Disappearing-Filament Pyrometer Lamp Superimposed on Target





(a) Filament too dark (b) Filament too bright (c) Equal brightness

Not suitable for contineous measurements

Disappearing Filament / Optical Pyrometer Characteristic Features:

Principle:

Planck Law; “For given λ intensity varies with temperature”.

- Most Accurate of all.
- Suitable only for T > 700 ^{0}C since it is based on visual brightness match by human operator.
- Used to realize Int. Pract. Temp. Scale, above 1063 ^{o}C.
- Calibration is made in terms of lamp heating current
- Manually lamp current is controlled until filament color matches with the color of incoming radiation i.e. *null balancing principle.*
- Not useable for continuous recording or automating control applications.
- More accuracy ±5^{0}C in the range of 850-1200 ^{0}C.

  ±10^{0}C in the extended range of 1100-1950 ^{0}C

Unit 3 Completes.