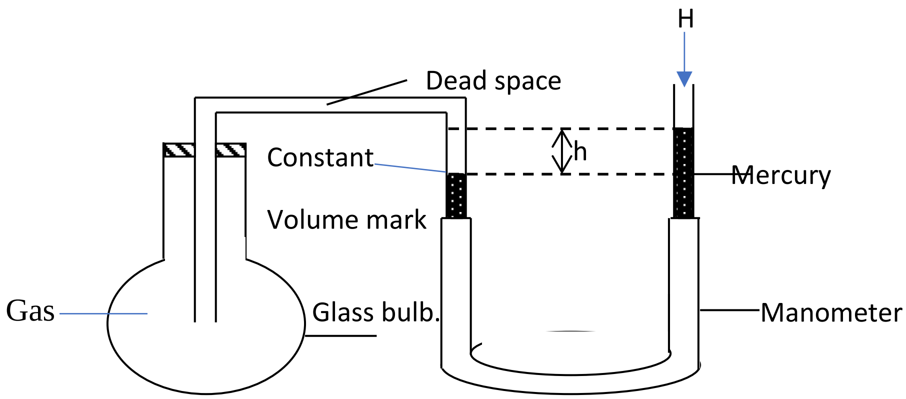
## S.5 PHYSICS

## P510/1 HEAT (CONTINUED……)

**CONSTANT –VOLUME- GAS THERMOMETER**




- **On Celsius scale**

- The bulb is immersed in pure ice and after some time the manometer is adjusted to bring mercury to the constant volume mark. (to ensure constant volume of the trapped gas).
- The difference in the mercury levels "$h_0$" is measured using a meter rule and recoded.
- The pressure the gas exerts at ice point is calculated from $P_0 = H + h_0$ where H is the atmospheric pressure.
- The above procedure is repeated when the bulb is immersed in pure steam from boiling water and the surrounding whose temperature **θ** is required.
- The differences in mercury levels "$h_{100}$" and "$h_\theta$" in each case are measured using a metre rule and recoded respectively.
- The pressures $P_{100}$ and $P_\theta$ are calculated respectively.
- The unknown temperature is the calculated from,

  $\theta = \left(\frac{P_\theta - P_0}{P_{100} - P_0}\right) x100^\circ C.$

- **On thermal dynamic scale**

- The bulb is immersed in a mixture of pure ice, pure water and pure steam existing in equilibrium and the difference in the mercury levels **"$h_{tr}$"** is measured using a metre rule and recoded.
- The pressure at triple point of water is obtained from $P_{tr} = H + h_{tr}$
- The above procedure is repeated when the bulb is immersed in the surrounding whose temperature **T** is required and the difference in the mercury levels "**$h_T$**" is measured and recoded and the pressure $P_T$ obtained.
- The unknown temperature T of the surrounding is then calculated from

$T = \left(\frac{P_T}{P_{tr}}\right) x273.16K.$

**Sources of errors**

(i) Thermal expansion of the bulb.
(ii) The gas in the dead space is not at the temperature as that in the bulb.
(iii) Capillary effects at the mercury surfaces.

**Such corrections are carried out as follows;**

- A predetermined estimated correction of temperature due to expansion of the bulb is added to the observed temperature measured by the thermometer or the bulb is made out of hard glass like Pyrex.
- The dead space is narrowed so as to contain a small fraction of the total mass of the gas to minimize temperature changes due to much air in the dead space.
- The capillary effect of the mercury is minimized by widening the manometer tubes.

NB: The unknown temperature can be calculated using the differences in the mercury level for a constant volume gas thermometer as below.

$\theta = \left(\frac{h_\theta - h_0}{h_{100} - h_0}\right) x100^{\circ}C.$

Example

1. In constant volume gas thermometer, the following observations were recorded on a day when the barometric reading was 760mmHg.

| | Reading in closed limb (mm) | Reading in open limb (mm) |
|---|---|---|
| Bulb in pure ice | 126 | 112 |
| Bulb in steam | 126 | 390 |
| Bulb at room temperature | 126 | 157 |

i) State the thermometric property of the thermometer
ii) Calculate temperature as measured by the thermometer

**Solutions:**

**i.** The pressure of a fixed mass of a gas at constant volume.

ii. From the table $h_o$=112-126=-14mmHg
$h_\theta$=157-126=31mmHg
$h_{100}$=390-126=264mmHg

$$\theta = \left(\frac{h_\theta - h_o}{h_{100} - h_o}\right) \times 100 = \left(\frac{31+14}{264+14}\right) \times 100 = 16.18^o C$$

2. The pressure at triple point of water recorded using a constant volume gas thermometer is $4.20 \times 10^4$ $Nm^{-2}$ and an unknown temperature T is $4.80 \times 10^4$ $Nm^{-2}$. Calculate the unknown temperature T on the thermodynamic scale.

$$T = \left(\frac{P_T}{P_{tr}}\right) x273.16K. = \frac{4.80X10^4}{4.20X10^4} X\ 273.16K = 312K$$

**Advantages of gas thermometers**

- Gas thermometers are very accurate since their thermometric properties vary linearly with temperature.
- Gas thermometers measure temperature over a wide range.

**Disadvantages of gas thermometers**

- Gas thermometers are very bulky
- Gas thermometers have a slow response to temperature changes because gases are poor conductors of heat.
- Gas thermometers cannot give direct readings

**NB: Question 1**

Explain why gas thermometers are used to calibrate other thermometers.

- The fact that thermometric properties of gas thermometers vary linearly with temperature, gas thermometers are very accurate thus used as standard thermometers for calibrating other thermometers.

**Question 2**

State any one advantage why gases are used in thermometers

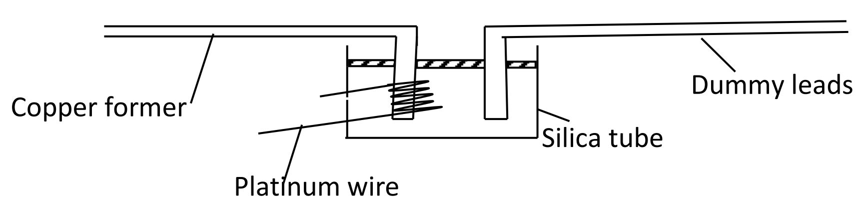
- All gases have the same coefficient of volume expansion as long as the gas pressure is low.

**THE PLATINUM RESISTENCE THERMOMETER.**

This uses the principle that the resistance of a metal changes with temperature.

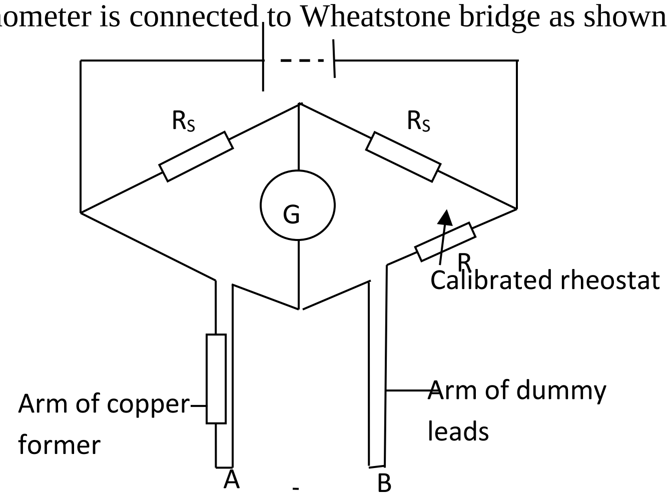
- **Structure**

It is a thin platinum wire wound on a mica/copper former. Such arrangement is fixed into a silica tube together with dummy leads which are identical to the copper former as shown below.



- **Action**

  The thermometer is connected to Wheatstone bridge as shown below




**On Celsius scale**

- The arm of the platinum wire is immersed in steam from boiling water at $100^0C$ and rheostat **R** is adjusted until when the galvanometer shows no deflection.
- The value of the rheostat at this temperature **$R_{100}$** is read and recorded.
- The above procedure is repeated when the arm of platinum wire is immersed in ice – water mixture at $0^0C$ and a liquid of unknown temperature **θ** such that the value of the rheostat in each case **$R_0$** and **$R_\theta$** are also read and recorded respectively.
- Assuming resistance of platinum wire to vary linearly, uniformly and continuously with temperature, the unknown temperature θ of the liquid is given by θ =$\left(\frac{R_\theta - R_0}{R_{100} - R_0}\right) x100°C.$

**On thermal dynamic scale**

- The arm of the platinum wire is immersed in a mixture of pure ice, pure water and pure steam existing in equilibrium.
- The rheostat **R** is adjusted until when the galvanometer shows no deflection and the value of the rheostat at this temperature **$R_{tr}$** is read and recorded.
- The above procedure is repeated when the arm of platinum wire is immersed in a liquid of unknown temperature **T** such that the value of the rheostat **$R_T$** is also read and recorded.
- Assuming resistance of platinum wire to vary linearly, uniformly and continuously with temperature, the un known temperature θ of the liquid is given by T =$\left(\frac{R_T}{R_{tr}}\right) x273.16K.$

**Advantages of platinum wire thermometer**

- It is accurate since its resistance varies linearly with temperature.
- It can be used to measure over a wide range i.e. (-200℃ to 1200℃).

**Disadvantages of platinum wire thermometer**

- Platinum wire has a low conductivity and a high specific heat capacity thus takes long for an observation to be made.
- Due to the size the tube, this thermometer cannot be used to measure at a point.
- The thermometer is bulky.

**Question**

**Explain why platinum is preferred to other metals for use in resistance thermometer.**

(i) Platinum has a high coefficient of resistance i.e. a small change in temperature produces appreciable change in resistance.

(ii) Platinum has a very high melting point.

(iii) Platinum is readily available in a state of high purity.

**Example**

1. The resistance R of platinum wire at temperature $\theta^oC$ as measured by mercury-in-glass thermometer is given by; $R_\theta=R_0(1+a\theta+b\theta^2)$ where $a=3.8x10^{-3}K^{-1}$ and $b=-5.6x10^{-7}K^{-2}$. Calculate the temperature of platinum thermometer corresponding to $200^oC$ on glass scale.

**Solutions:**

Since both scales agree at fixed points, and that for platinum thermometer $R_\theta = R_o\left(1+a\theta+b\theta^2\right)$ then;

$$\Rightarrow R_{100} = R_o\left(1+a\times 100+b\times 10000\right)$$

$$R_{200} = R_o\left(1+a\times 200+b\times 40000\right)$$

$$\therefore \theta = \left(\frac{R_\theta - R_o}{R_{100} - R_o}\right)*100$$

$$\theta = \left(\frac{200a+40000b}{100a+10000b}\right)*100$$

$$\theta = \left(\frac{200x3.8x10^{-3} + 40000x - 5.6x10^{-7}}{100x3.8x10^{-3} + 10000x - 5.6x10^{-7}}\right)x100^0$$

$\theta=197$℃.

**2.** The resistance of platinum thermometer is $2.04\Omega$ at ice point and $3.02\Omega$ at the steam point.

i) What should be the temperature of platinum wire so as to have a resistance of $9.24\Omega$?

ii) If a constant-pressure thermometer had been used, the same temperature would correspond to $1040^oC$. Explain the deviation.

**Solutions:**

i) $\theta = \left(\frac{9.24-2.04}{3.02-2.04}\right)x100^\circ C = 734.7$℃.

ii) The variation of platinum resistance with temperature is different to the variation of volume of a fixed mass of dry gas with temperature thus the two thermometers give unique readings.

3. The resistance of the platinum wire at tripple point of water is $45\Omega$ and that of sand is $33\Omega$. Calculate the absolute temperature of the sand.

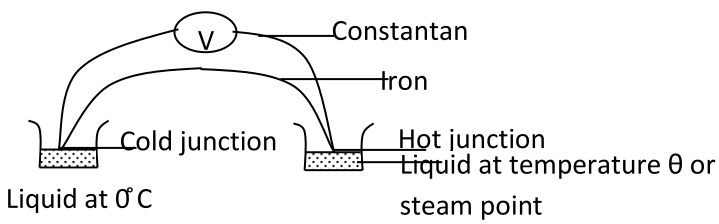
T =$\left(\frac{R_T}{R_{tr}}\right)x273.16K = \left(\frac{33}{45}\right)x273.16K = 200.3\Omega$

**THERMOCOUPLES**

Whenever two different metals are in contact, an emf is set up at the point of contact. The magnitude of this emf depends on the temperature at the junction of the two metals and therefore the effect is called seebeck or thermoelectric effect.

- **Structure**

Two metal wires of different materials are joined to form a junction.




- **Principle**

It works on the principle that when two different metals e.g. iron and constantan are joined together with their junctions kept at different temperatures, an e.m.f is induced in the circuit and that this e.m.f depends on the temperature difference between the junctions i.e. $\mathbf{E_\theta = A\theta + B\theta^2 + C\theta^3 + \ldots}$ Where **A, B** and **C** are constants.

- **Action**

**On Celsius scale**

- The voltmeter reading $\mathbf{E_0}$ is read and recorded when both the cold junction and hot junction are immersed in pure ice.
- The hot junction is then immersed in pure steam with the cold junction still in ice and the voltmeter reading $\mathbf{E_{100}}$ is read and recorded
- With the cold junction still in ice, the hot junction is dipped in a liquid whose temperature is required such that the voltmeter reading $\mathbf{E_\theta}$ is read and recorded.
- Assuming e.m.f generated to vary linearly, uniformly and continuously with temperature, θ =$\left(\frac{E_\theta - E_0}{E_{100}-E_0}\right)x100^\circ C$ for $E_{0=}0V$.

**On thermal dynamic scale**

- The hot junction of the thermal couple is immersed in a mixture of pure ice, pure water and pure steam existing in equilibrium and the voltmeter reading $\mathbf{E_{tr}}$is read and recorded.

- The above procedure is repeated when the hot junction of the thermal couple is immersed in a liquid of unknown temperature **T** such that the voltmeter reading $\mathbf{E_T}$ is also read and recorded.
- Assuming e.m.f generated to vary linearly with temperature, T $=\left(\frac{E_T}{E_{tr}}\right) x273.16K$.

**Conditions for e.m.f to be generated between junctions**

- The junctions must be of different metals
- The junctions must be at different temperatures

**Sources of errors when using a thermocouple**

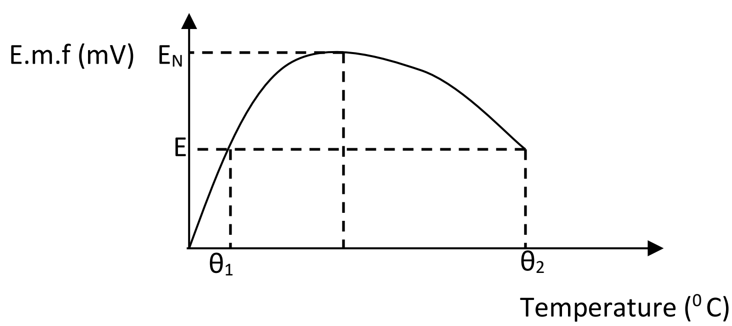
- Leakages due to poor insulation means
- Leakages due to strained thermocouple wires
- Stray thermo electric e.m.fs due to several contacts involved during measurements

**Advantages of thermocouples**

- It can be used to measure temperature at a point.
- Metals used always have a high conductivity and low s.h.c thus suitable for measuring rapidly varying temperatures.
- The thermometers are portable since they are robust and compact.
- It can be made to measure temperature directly by connecting it to an ammeter calibrated to read temperature.

**Disadvantages of thermocouples**

- E.m.f of a thermocouple does not vary linearly with temperature.
- Thermocouples can give two similar readings corresponding to different temperature values as shown below.




**NB:**

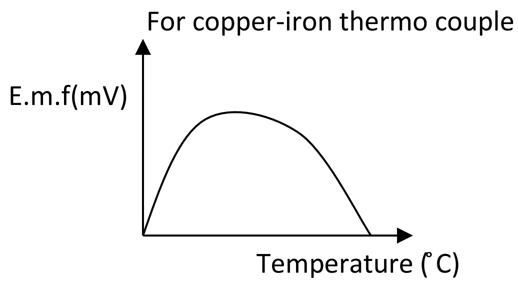
Temperature corresponding to "$E_N$" is called the **<u>neutral point</u>** of thermocouple.

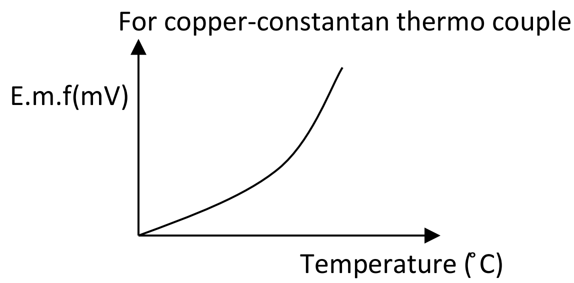
**Definition:**

Neutral temperature of thermocouple is the maximum temperature of thermocouple just below which its e.m.fs vary fairly linearly.

***For this very reason, thermocouples are only used as thermometers at temperatures below its neutral temperature.***

**Variation of e.m.fs with temperature**




**Question**

***Explain why a thermocouple can be used to measure rapidly fluctuating temperatures***

This is because it has a very small heat capacity and therefore, it has very little effect on the temperature of the body being measured.

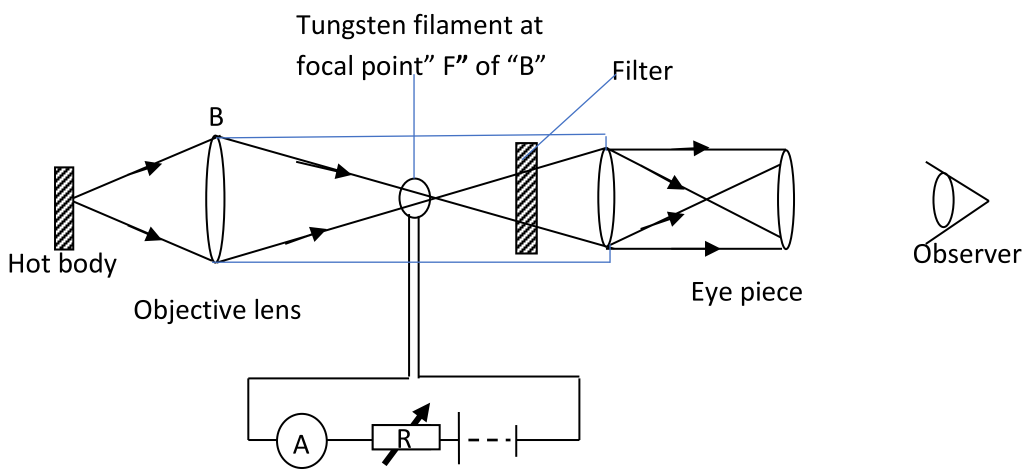
**PYROMETRY**

This is the measurement of very high temperatures.

**Radiation Pyrometers**

A radiation pyrometer is an instrument used to measure high temperatures of a body based on the radiations emitted by the body. Such instruments are of two types i.e. optical pyrometer which responds to only visible radiation and total radiation pyrometer which responds to both visible and infrared radiation.

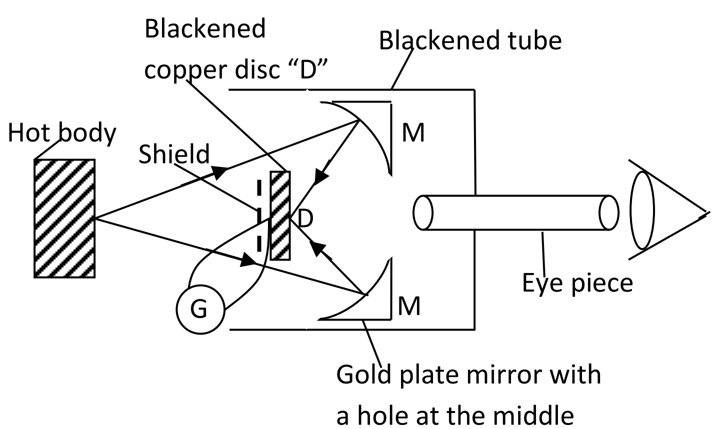
**Optical pyrometer**



**Action**

- The eye piece is focused on the filament receiving radiations from a body whose temperature is to be determined.
- The objective lens is adjusted until when the radiations from the body lie in the same plane with the filament.
- At this point both the object and the filament appear red hot as seen through the filament placed at the focal point of the objective lens.
- The rheostat R is adjusted until when the filament and the radiations from the body have the same appearance i.e. when the object just disappears from the back ground of the filament.
- Temperature of the hot body is read from the ammeter **"A"** calibrated to measure temperature in **"Kelvin".**

**Total radiation pyrometer**




- Radiations from the hot body fall on mirror "M" and get reflected to the copper disc "D".
- The disk is heated by the radiations until it reaches an equilibrium temperature i.e. temperature at which its rate of heat loss = its rate of heat gain.
- An emf is set up and the sensitive galvanometer G deflects
- The temperature of the body is read and recorded from the deflection of the galvanometer which is calibrated to measure temperature in **Kelvin.**

***REVISION QUESTIONS***

1) Temperature $\boldsymbol{\theta}$ of a liquid is determined using a resistance thermometer and a constant-volume gas thermometer and the following measurements were obtained.

$R_o$= 2.00Ω, $R_{100}$=2.50 Ω, $R_\theta$=2.09 Ω

$P_0$ = 4.00atm, $P_{100}$=5.50atm, $P_\theta$=4.25 atm

Determine the value of θ for each thermometer and account for their discrepancy

2) The resistance R of platinum wire at various temperatures on a mercury-in-glass scale is given by

| T/$^oC$ | 0 | 20 | 40 | 60 | 80 | 100 |
|---|---|---|---|---|---|---|
| R/Ω | 10.0 | 10.26 | 10.6 | 11.02 | 11.48 | 12.00 |

Use graphical method to determine;

(i) Temperature as read from platinum wire thermometer corresponding to 65$^oC$ on mercury-in-glass thermometer

(ii) Temperature as read from mercury-in-glass thermometer corresponding to 45$^oC$ on platinum wire thermometer.

3) A particular resistance thermometer has a resistance of 30Ω at ice point, 41.58Ω at steam point and 34.59Ω when immersed in a boiling liquid and constant-volume-gas thermometer reads $1.33\times10^5$pa, $1.62\times10^5$pa, $1.528\times10^5$pa at the three points stated above respectively. Calculate temperature of the boiling liquid as measured by each thermometer.

4 (a)(i) Define the terms heat and temperature.

(ii)State four quantities of a good thermometric property.

(b)Describe how you would estimate absolute zero temperature.

(c) Describe how unknown temperature of a liquid can be measured by liquid-in-glass thermometer.

(d) Use kinetic theory of gases to explain the existence of absolute zero temperature.

(e) A copper-constantan thermocouple with its cold junction at 0℃ had an e.m.f of 4.28mV when the other end is immersed in pure steam and 9.29mV when the second end is immersed in a liquid at 200℃. Given that its e.m.f is related to temperature difference θ by the expression $\mathbf{E_\theta = A\theta + B\theta^2}$ determine the values of A and B.

5(a)(i) Define the terms Fixed point and Lower fixed point.

(ii) In tabular form state any four kinds of thermometers with their corresponding thermometric property.

(b)(i) Describe the structure of platinum resistance thermometer.

(ii)Explain why constant –pressure thermometer gives a slow response.

(c) One Junction of a thermocouple is placed in melting ice while the other is inserted into a bath whose temperature as measured by high temperature mercury- in- glass thermometer is T°C as shown in the table below.

| T//°C | 0 | 101 | 212 | 302 | 425 | 552 | 635 |
|---|---|---|---|---|---|---|---|
| e.m.f/mV | 0 | 0.75 | 1.40 | 2.33 | 3.22 | 4.35 | 5.14 |

By graphical method find;

(i) Temperature as measured from thermocouple thermometer corresponding to 380°C on mercury-in-glass thermometer.

(ii) Temperature as read from mercury-in-glass thermometer corresponding to 250°C on the thermocouple thermometer.

6(a)(i) Define a thermometer.

(ii) Describe how unknown temperature of a liquid can be determined by platinum resistance on thermodynamic scale.

(b)(i) State two advantages and two disadvantages of thermocouples.

(ii) In constant-volume gas thermometer, the following observations were recorded on a day when barometric reading was 760mmHg.

| | **Reading in closed limb (mm)** | **Reading in the open limb (mm)** |
|---|---|---|
| Bulb in pure ice | 130 | 123 |
| Bulb in steam | 130 | 165 |
| Bulb at room temp | 130 | 178 |

State the thermometric property of the thermometer and calculate the temperature value as measured by the thermometer.

(c) Explain the following in relation to liquid – in –glass thermometer.

(i) Mercury is the best liquid for measuring high temperatures.

(ii) Alcohol is the best liquid for measuring small temperatures.

(d) Sketch graphs of e.m.fs against temperature for;

(i) Copper – iron thermocouple.

(ii) Iron-constantan thermocouple.

7(a)(i) Define neutral point of a thermocouple.

(ii) Describe how total radiation pyrometer can be used to determine temperature of the sun.

(b)(i) State the principle of operation of the thermocouple.

(ii) Temperature of a liquid is determined using a resistance thermometer with the following measurements.

$R_o = 4.53\Omega$, $R_{100} = 8.54\Omega$ $R_\theta = 7.59\Omega$

Calculate the temperature value as measured by the thermometer.

8 (a)(i) State the requirements for establishing thermal dynamic scale of temperature.

(ii) Explain why scales of temperature based on different thermometric properties may not agree.

b) (i) With the aid of a labeled diagram, describe how a constant volume gas thermometer is used to measure temperature on thermal dynamic scale.

(ii) Give disadvantages and advantages of gas thermometers.

c) If a wire has a resistance of 4Ω at the triple point of water, find its resistance at $80^oC$.

d) (i) What are Pyrometers?

(ii)With the aid of a diagram, describe how the optical pyrometer is used to measure temperature of a hot body.

9 (a) What is meant by the following terms;

i) Absolute zero temperature

ii) Triple point of water

b) i) Describe the steps taken to establish scales of temperature.

ii) State three advantages of thermocouple over an electrical resistance thermometer

c) With a well labeled diagram describe how room temperature can be measured using platinum wire thermometer.

d) i) State and explain the source of inaccuracies while using mercury-in glass thermometer

10(**a)** Explain the following observation as applied to gas thermometer

i) Constant-volume gas thermometer is preferred to constant –pressure gas thermometer.

ii) Gas thermometers are used to calibrate other thermometers.

b) (i) Explain why it is possible for two different bodies at different temperatures may have the amount of heat.

(ii) Resistance of platinum wire is $\mathbf{6.750R_o\Omega}$ at room temperature. Calculate the value of room temperature if temperature coefficient of platinum is $2.07\text{x}10^{-4}K^{-1}$.

c) Resistance of a metal wire at temperature θ measured on standard scale is given by $\mathbf{R_\theta=R_0(1+A\theta+B\theta^2)}$ where **A** and **B** are constants. Given that $\mathbf{B = 10^{-3}A}$, calculate the temperature value on the resistance thermometer corresponding to $60^0C$ on standard scale.

d) (i) State corrections made on constant-volume gas thermometer before being used to measure temperature.

(ii) Explain how the corrections mentioned in d(i) above are carried out.