TOPIC: HEAT AND THERMODYNAMICS

SUB TOPICS

1.THERMOMETERS

2.HEAT TRANSFER

- Thermal Conduction
- Thermal Convection
- Thermal Radiation

3.THERMALDYNAMICS.

MODULE 1: TEMPERATURE AND THERMOMETRY

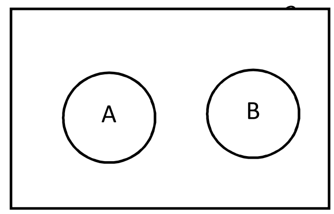
1. **HEAT** - Is the form of energy that transfer between two or more points due to the temperature difference.

S.I. Unit of heat energy is Joule (J) or Calorie (Cal).

1Cal = 4.2 J

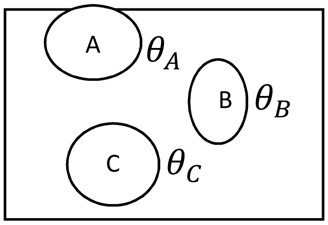
- Calorie is used in many practical applications e.g. the energy value of food is specified in kilocalories.

2. **CALORIMETER** – Is the device which used to measure the amount of heat energy of a substance.
3. **TEMPERATURE** – Is the degree of hotness or coldness of a body. The S.I. Unit of temperature is kelvin (k) or ℃ or °F $or\ Rankie\ (R)$.
4. **THERMOMETER** – Is the device which used to measure the temperature of the body.
5. **THERMODYNAMICS** – Is the branch of physics which deals with the study of transformation of heat energy into other form of energy and vice – versa.
6. **THERMAL EQUILIBRIUM.** Two bodies are said to be in thermal equilibrium if are maintained at the same temperature.



If $\theta_A = \theta_B$, then body a and b are said to be in thermal equilibrium.

7. **THERMAL CONTACT.** – Two bodies are in thermal contact with each other if there is heat energy exchange occurs between them in absence of microscopic work done by one to the another.
8. **PRINCIPLE OF CALORIMETER.** State that ‘When a hot body is mixed with cold body the heat loss by hot body is equal to heat gained by cold body’.
Heat loss by hot = Heat gained by cold body
$M_1C_1(\theta_1 - \theta) = M_2C_2(\theta - \theta_2)$
$\theta = Equilibrium\ temperature$
9. **EQUILIBRIUM TEMPERATURE**
Is the equal temperature obtained after mixing the hot and cold body.
10. **ZEROTH LAW OF THERMODYNAMICS**
State that “When the thermodynamics systems A and B are separately in thermal equilibrium with a third thermodynamics system C, then the system A and B are in thermal equilibrium with each other also”



If $\theta_A = \theta_B$ and $\theta_A = \theta_C$ then $\theta_B = \theta_C$. It is called Zeroth Law because other laws of thermodynamics logically come after this law.

IMPORTANT OF ZEROTH'S LAW OF THERMODYNAMICS

This law helps us to explain the concepts of temperature and thermal equilibrium.

11. **THERMOMETRY** – Is the science of temperature and its measurement.
12. **THERMOMETRIC SCALE** – Is the scale which is used for measurement of temperature.

    PRINCIPLE: The basic principle of a thermometer is that two bodies in thermal contact and thermal equilibrium have same temperature. Every thermometer is based on physical property that changes in temperature.

Thermometry involves three steps.

1. Construction. In constructing a thermometer, the variation in physical property is to be selected depends upon on temperature range to be measured.
2. Calibration. Next step is to mark the two fixed points. The scales are made by dividing the interval between two fixed points into equal parts.
3. Sensitiveness of thermometer.

The thermometer is said to be sensitive if:

a) Read the temperature of a body with which it is in contacts quickly.
b) Shows even small variation in temperature.
c) Does not absorb large quantities of heat from the body whose temperature is to be measured for its own heating.

THERMODYNAMICS TEMPERATURE SCALE.

Is a standard temperature scale adopted for the scientific measurements.

- This scale uses the triple point of water as the upper fixed point and absolute zero as the lower fixed point.
- It can be denoted by using capital letter 'T' and S.I. Unit of Thermodynamics temperature scale is Kelvin(K).

FACTORS FOR ESTABLISHMENT OF TEMPERATURE SCALE.

1. The fixed temperature point must be known.
2. Thermometric property of the substance.
3. The values of thermometric property at the steam and ice point are found (X_{100} and X_0) and ($X_{100} - X_0$) gives the fundamental interval of scale.

1. **THE FIXED POINT OF THE TEMPERATURE.**

   For any temperature scale its necessary to have two fixed points. The fixed points enable calibration of thermometer based on the scale used.

FIXED POINT(S) – Is a single temperature at which it can confidently be expected that a particular physical event always takes place.

Fixed points are temperatures at which particular physical properties manifest themselves.

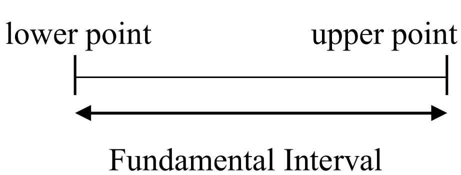
Examples of fixed points of temperature:

i. Lower point (Ice point) and Upper fixed point (Steam point)
ii. Triple point of water
iii. Absolute zero temperature

- **LOWER FIXED POINT**

Is the temperature of pure melting ice. It's value is 0℃(273k).

- **UPPER FIXD POINT**
  Is the temperature of the boiling point of water (substance) under standard atmospheric pressure.
- **ICE POINT** - is the temperature in which the pure ice can exit in equilibrium with water at standard atmospheric pressure (760mmHg). Temperature of ice point =0°$(273.15k)$
- **STEAM POINT** - Is the temperature at which pure water can exist in equilibrium with water vapor at standard atmospheric pressure. Temperature at the steam point is$100°c(373.15K)$.



FUNDAMENTAL INTERVAL (N)

- Is the difference in temperature between the upper fixed point and lower fixed point.
- Is the interval between the upper fixed point and lower fixed point.

$N = T_U - T_L \quad or$

$N = X_u - X_L$

T_U = temperature of upper fixed point

T_L=temperature of lower fixed point

If the fundamental interval is known, then it is early to make different gradual division (scale) on that thermometer

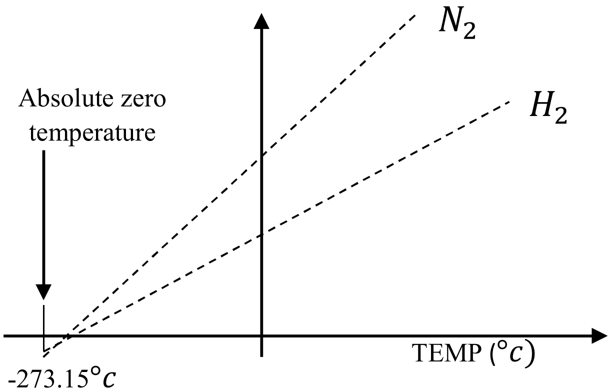
- **TRIPLE POINT OF WATER**
  Is the unique temperature at vapor can exist in dynamic equilibrium.
  The triple point of water occurs at a pressure of 4.6mmHg and temperature of triple point of water is 273.16 k $(0.01°c)$.
  Note:
  1)Triple point are unique, occurs at the same temperature and pressure. i.e. It does not affect by change in pressure and presence of impurities. For this reason, triple point of water is used as fixed point in modern thermometers.
  2) Ice and stream and stream point are not unique, as they can change as change of pressure and presence of impurities.

ABSOLUTE ZERO TEMPERATURE

Is the temperature at which the volume or pressure of a gas theoretically approximately is equal to zero.

The value of absolute zero temperature is – 273.15 $°c$

Graph of P/V against temperature



Under absolute zero temperature, the activity of the molecules released where speed of the molecules is theoretically reduced to zero. Hence there is no momentum, no forces experienced and no pressure exerted by the gas. Therefore, the kinetic energy of the gas molecules is equal to zero

CONVERSION OF TEMPERATURE SCALE FROM ONE SCALE TO THE ANOTHER SCALE

Relation used: -

$$= \frac{\text{Temp on one scale} \ - \text{lower fixed point}}{upper\ fixed\ point - lower\ fixed\ point}$$

$$= \frac{Temp\text{ on other scale} - \text{lower fixed point}}{upper\ fixed\ point - lower\ fixed\ point}$$

$$\frac{c - o}{100 - 0} = \frac{F - 32}{212 - 32} = \frac{R - 0}{80 - 0}$$

$$\frac{C}{100} = \frac{F - 32}{180} = \frac{R}{80}$$

CELCIUS TEMPERATURE SCALE

Is the temperature scale which used two fixed point the ice point and stream point.

$$\theta = \frac{5}{9}(F - 32)$$

θ= Temperature in $°c$. Scale

F= definition one-degree Celsius is $\frac{1}{273.16}$ of the difference between absolute zero and the triple point water.

KELVIN TEMPERATURE SCALE

Is the standard temperature scale adopted for scientific measurement and uses only one fixed point i.e. triple point of water.

Kelvin temperature scale is defined by the equation $T = (\theta + 273.15)K$.

- Kelvin scale which does not depend upon any physical property of thermometric of substance used. It is also ‘Absolute scale of temp’
- Change of temperature in ℃ is equal to change in temperature in Kelvin.

Note that:

- Thermodynamics temperature scale is said to use one fixed point simply because the theoretical temperature (OK) has never been measured practically.
- The kelvin scale is the temperature scale which has no negative temperatures.

2. THERMOMETRIC PROPERTY.

Is the property of a substance which varies linearly and continuously with temperature sometimes thermometric property is known as physical property of a thermometer.

Let $X_T =$ thermometric property at any temperature T.

$X_T \alpha T \quad , \quad X_T = K T$

K = Constant of proportionality

Examples of thermometric Property

1. Electromotive forces (emf)
2. Resistance of a wire
3. Volume of a gas at constant pressure.
4. Pressure of a gas at constant volume
5. Volume of a liquid.
6. Length of liquid column.
7. Color of radiation emitted by hot body.
8. Root mean square speed of a gas molecules.
9. Electric current etc.

QUALITY OF GOOD THERMOMETRIC PROPERTY.

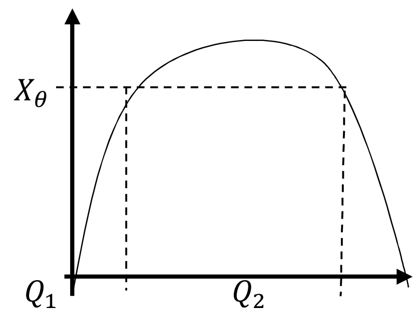
1. They have unique value at a particular temperature.
2. It should vary continuously and linearly with temperature.
3. They are sensitive to the temperature change.
4. They are easily reproduced in laboratory (Reproducible).
5. It should be repeatable (Repeatability).

Note that:

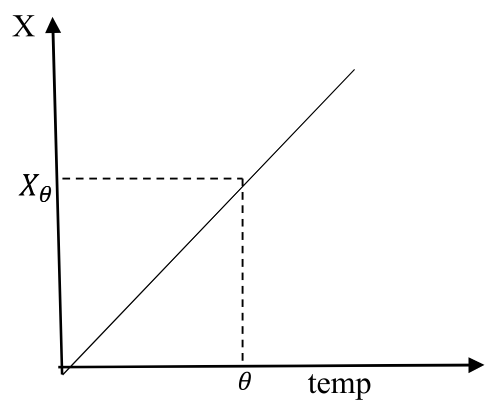
Each value of thermometric property should correspond to only one value of temperature.

This can be demonstrated by using the following graphs.

Graph I



Graph II



From the Graph I shows that X is unsuitable as the thermometric property because the single value of X_θ is corresponding to the temperatures θ_1 and θ_2. This leads to the confusion on the reading.

Graph II Show that the single value of X_θ is corresponding to the unique temperature, θ this behaves as good thermometric property

RELATIONSHIP BETWEEN TEMPERATURE AND VALUE OF THE THEMOMETRIC PROPERTY IN KELVIN SCALE

In order to measure temperature in kelvin scale, the triple point of water (273.16k) and its corresponding thermometric property (x_{TR}) must be known.

method 1 from the definition

$X_T = KT, X_{TR} = KT_f$ $\frac{KT}{KT_f}$ $\frac{x_T}{X_{TR}}$

$$T = \left(\frac{x_T}{X_{TR}}\right) T_f$$

$T_f = T_{tr}$

Temp at triple point.

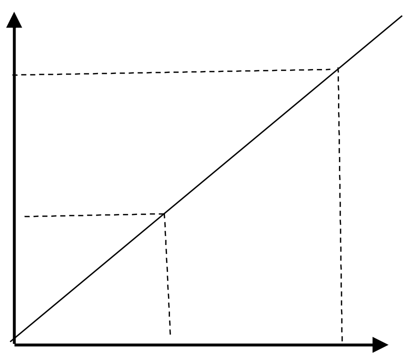
$$T = \left(\frac{x_T}{X_{TR}}\right) \times 273.16K$$

Method 2

By graphical method

since XT$\propto T$,

$X_{TR} = x_T$ X (Unit)



By equating the slope, we get

$$\frac{x_T}{T} = \frac{X_{TR}}{T_{TR}}$$

$$T = \left(\frac{X_T}{T_{TR}}\right) \times T_{TR}$$

For example:

1. For constant volume gas thermometer $P_T \propto T$

$$T = \left(\frac{P_T}{P_{TR}}\right) \times 273.16K$$

2. for the liquid thermometer

$$T = \left(\frac{V_T}{V_{TR}}\right) \times 273.16K$$

3. for the platinum resistance thermometer

$$T = \left(\frac{R_T}{R_{TR}}\right) \times 273.16K$$

4. For an ideal gas scale

$$T = \left[\frac{(PV)_T}{(PV)_{TR}}\right] \times 273.16K$$

SOLVED EXAMPLES

TYPE A

EXAMPLE 01

a) Define Celsius temperature scale

b) A particular constant volume gas thermometer registers a pressure of 1.937$\times 10^4$ Pa at the triple point of water and 2.168 10^4 Pa at the boiling point of the liquid. According to this thermometer, what is the boiling point?

Solution

b) $T = \left(\frac{P_T}{P_{TR}}\right) \times 273.16K$

$$= \left[\frac{2.16 \times 10^4}{1.937 \times 10^4}\right] \times 273.16K$$

$\underline{T = 304.61K}$

EXAMPLE 02

a) What are the requisites of a thermometer?

b) The pressure recorded by the constant volume gas thermometer at a Kelvin temperature T is 4.8×10^4 Pa. Calculate T if the pressure at the triple point is 4.2×10^4Pa .

Solution

i. The thermometer should be small in size and capable of reading low as well as high temperature

ii. It should give the same reading for the same temperature at all times and at all places.

iii. It should respond to very small changes of temperatures.

The thermometer should absorb least amount of heart from the body whose temperature is to be measured and it should show the temperature quickly.

iv. The physical property used to construct the thermometer should have a linear relationship with temperature.

v. The thermometer should not take much time to respond to a changing temperature

a) $T = \left[\frac{4.8\times10^4}{4.2\times10^4}\right] \times 273.16K$

$\boldsymbol{T = 312.18K}$

EXAMPLE 03

A certain platinum resistance thermometer has a resistance of 90.451Ω when its bulb is placed in a triple point of water. What is the temperature defined by the resistance thermometer when its bulb is placed in a place such that its resistance is 98.3 Ω

Solution

$$T = \left[\frac{R_T}{R_{TR}}\right] \times 273.16K$$

$$= \left[\frac{98.35}{90.45}\right] \times 273.16K$$

T=

EXAMPLE 04

The triple points of Neon and Carbon dioxide are 24.57k and 216.55k respectively. Express the temperatures on Celsius and Fahrenheit scale

Solution

- Temperature point on Celsius scale

  $t = T$ - 273.15K

  Triple point of Co_2=

  216.55 - 273.15 = -24.54°

- Temperature on °F scale

  t(°F) $= \frac{9}{5} + 32$

  Triple point of Neon gas

  $= \frac{9}{5} \times -248.88 + 3$

$= -415.44$°F

  Triple point of Co_2

  $=\frac{9}{5}\ (-56.6) + 32 = -69.88$°F

Example 05

a) The triple point of water is a standard fixed point in modern thermometer. Why?

b) Two absolute scales A and B have triple points of water defined to be 200A and 359 B. What is the relationship between T_A *and* T_B ?

Solution

a) The triple point of a substance is a unique i.e. occurs at one particular pressure and temperature. On the other hand, melting point of ice and boiling point of water change due to the change of pressure and the presence of impurities on water.

b) Triple point of water on absolute scale A and B are 200A and 350 B respectively value of 1-degree scale of

A=$\frac{273.16}{200}$

Value of temperature on absolute scale

$$A = \frac{273.16}{200} \times T_A$$

Value of temperature on absolute scale B =$\frac{273.16}{350} \times T_B$

As T_A *and* T_B represent the same temperature

$$\frac{273.16T_A}{200} = \frac{273.16T_B}{350}$$

$$T_A = \frac{200}{350} \quad T_B = \frac{4}{7}T_B$$

<u>EXAMPLE 06</u>

a) Define the following;

(i) Thermodynamics coordinates

(ii) Thermodynamic state

(iii) Thermal equilibrium

b) State the Zeroth's law of Thermodynamics and explain how the concepts of temperature arises from the Zeroth law

i. Define Ideal gas temperature.

ii. A constant volume gas thermometer is immersed in water at the triple point and the pressure p_3 recorded, then it is immersed in a thermostatic bath at θ and the pressure Pθ recorded. The experiment is repeated for different values of P_3. Table below gives the result. Find the deal gas temperature

$p_3(mmHg)$	1000.00	750.00	500.00	250.00
$p_{\theta}(mmHg$	1535.30	1151.76	767.82	383.75

Triple point of water

$$T_{TR} = 273.16$$

Solution

a) Refer to your notes

b)

i. Idea gas scale is the temperature scale which is identical to the thermodynamic scale, which is quite independent of the properties of any individual substance

ii. ideal gas temperature here can be obtained by using average method

$$\theta = \frac{\frac{1534.3}{1000} + \frac{1151.76}{750} + \frac{767.82}{500} + \frac{383.95}{250}}{4} \times 273.16K$$

$\boldsymbol{\theta = 419.47}$

EXAMPLE 07

A temperature T can be defined by

$$T = \left(\frac{x}{x_f}\right) T_f$$

Where T_f is the assigned temperature of a fixed point and X and X_f are the value of a thermometric property of a substance at T and T_f respectively. On the Ideal-gas scale the fixed point is the triple point of water and $T_f = 273.16K$

i) List four thermometric properties which properties of a gas are taken as standard

ii) Explain what is meant by fixed point and triple point of water

iii) The pressure recorded in a certain constant – volume gas thermometer at the triple point of water and the boiling point of a liquid were 600 mm of Hg ad 800 mm of Hg respectively. What is the apparent temperatures of the boiling point? however it was found that the volume of the thermometer increased by 1% between the two temperatures obtain a more accurate value of the boiling point

Solution

i. Refer to your notes
ii. Refer to your notes
iii. Apparent temperature of the boiling point.

$$T = \frac{800}{600} \times 273.16K = 364.21K$$

- True pressure at the boiling point is

$$800 + 800 \times \frac{1}{100} = 808\ mmHg$$

$$T = \frac{808}{600} \times 273.16K$$

EXAMLE 08

At the point of water whether the relation amount of ice water and vapor fixed or not explain.

Solution

At the triple point of water, the temperature and pressure are fixed. For water, triple point temperature is 273.16K (or 0.07°C) and triple point pressure is 0.46cm of Hg column. However, the relative amount of three phases at triple of water are not unique. The relatives amount of three phases can be varied by adding or taking heat from the systems.

EXAMPLE 09

Two ideal gas thermometers A and B use oxygen and hydrogen respectively. The following observations are made

Temperature	Pressure thermometer	Pressure thermometer
Triple point of water	1.250× $10^5 p_a$	0.200× $10^5 p_a$
Normal melting	1.797× $10^5 P_a$	0.287× $10^5 p_a$

(a) What is the absolute temperature of normal melting point of Sulphur as read by thermometer A and B?

(b) What do you think is the reason for you for the slightly different answers from A and B? (The thermometers are not faulty). What further procedure is needed in the experiment to reduce the discrepancy between the two readings.

Solution

a) Let T be the melting point of sulfur for water

$$T = \left(\frac{P_T}{P_{tr}}\right) \times 273.16K$$

For thermometer A

$$T = \frac{1.797 \times 10^5}{1.250 \times 10^5} \times 273.16K$$

T= 392.69K

For thermometer B

$$\frac{0.287 \times 10^5}{0.200 \times 10^5} \times 273.16K$$

$$T = 391.98$$

b) The cause of slight different answer is that the oxygen and hydrogen gases are not perfectly ideal. To reduce the discrepancy, the reading should be taken as lower and lower pressures as in that case, the gases approach to the ideal gas behavior

Example 10

Answer the following

a)There were two fixed point in original Celsius scale as mentioned which were assigned the number 0℃ and 100℃ respectively. On the absolute scale, one of the fixed point is the triple point of water which on the Kelvin absolute scale is assigned the number 273.16K. What is the fixed point on this(Kelvin) scale?

b) The absolute temperature (Kelvin scale) T is related to the temperature tc on the Celsius scale by $t_c = -273.15$. Why do we have 273.15K in this relation and not 273.16?

c) what is the temperature of the triple point of water on an absolute scale whose unit interval size is equal to that of the Fahrenheit scale

Solution

a) The other fixed point on the Kelvin absolute scale is absolute zero itself

b) On Celsius scale 0℃ corresponds melting point of ice at normal pressure .The corresponding value of absolute temperature is 273.15K .The temperature 273.16K Corresponds to the triple point of water .For the given relation ,the corresponding value of triple point of water on Celsius scale =273.16-273.15=0.01℃

Fahrenheit scale and absolute scale re related by

$$\frac{T_F - 32}{180} - \frac{T_k - 273.15}{100} \quad - - - \text{(i)}$$

$$\frac{T_F - 32}{180} = \frac{T_R - 273.15}{100} - -\text{(ii)}$$

Subtracting (i) from (ii), we have

$$\frac{T_F - T_F}{180} \frac{T_K - T_K}{100} \quad OR$$

$$T_F - T_F = \frac{180}{100} \ (T_F - T_F) \text{ if } T_F - T_F = 1k$$

$$then\ T_F - T_F = \frac{180}{100} \times 1k = \frac{9}{5}$$

For the temperature of triple point i.e. 273.16K, temperature on the new scale is

$$= 273.16 \times \frac{9}{5} = 491.69$$

ASSIGGNMENT NO 01

1. **NECTA 2018 / P1 / 7**

i. Which type of thermometer is most suitable for calibration of other thermometers (01 mark)

ii. why at least two fixed points are required to define a temperature scale (02 marks)

a)

i. List two qualities which make a particular property suitable for use in practical thermometers (02 marks)

ii. Describe how mercury in glass thermometer could be made sensitive (02 marks)

b)

i. what is meant by triple point of water (01 mark)

ii. Evaluate the temperature in kelvin if the pressure recorded by a constant volume gas thermometer is $6.8 \times 10^4 Nm^{-2}$ given that the pressure at the triple point 273.16k is $4.6\times 10^4 Nm^{-2}$ (02marks)

2. When in thermal equilibrium at the point of water the pressure of helium in a constant volume gas thermometer is 1020 p_a. The pressure of the helium is 288 p_a when the thermometer is in thermal equilibrium with liquid nitrogen at its normal boiling point. What is the normal boiling point of nitrogen as measured using this thermometer?

Answer: 77.1 K.

3. The resistance of the element in a platinum resistance thermometer s 6.750Ω at the triple point of water and 7.166Ω at room temperature. What is the temperature of the room on the scale of the resistance thermometer? The triple point of the water s 273.16K. State one assumption you have made.

Answer: 289.995 K.

Assumption: The resistance of the of the element increases by the same amount for every degree rise in temperature.

4. In a constant volume gas thermometer, the pressure at the ice point (0°C) is 1.20$\times 10^4 p_a$and at an unknown liquid temperature T it is 1.08$\times 10^4 p_a$. Using P_T/Pice = T/273.15, Calculate, T. Find the new liquid temperature when the observed pressure is 1.04$\times 10^4$ p_a.

Answer: 291K, 237K.

RELATION BETWEEN TEMPERATURE AND VALUE OF THERMOMETRIC PROPERTY IN CELCIUS SCALE

In order to determine the temperature in °C scale the two fixed point must be known.

Let $X_L, X_U\ andX_T$ be thermometer of lower upper fixed point ad temperature T respectively

Method 01. Graphical method on plotting the graph of thermometric property (x) against temperature (T) always the strength line is obtained no matter the property is chosen because **there is equal increase in the value of temperature T** i.e. **this is due to the liner variation between thermometric** property with temperature

$$X_T \propto T, X_T = K_T$$

From the graph above, the points A, B and C are collinear point, then have the same slope.

Taking the slope

Slope of AB = slope AC

$\frac{X_T - X_L}{T - T_L} = \frac{X_U - X_L}{T_U - T_L}$

Taking reciprocal and simplifying, gives

$T = T_L + \left(\frac{X_T - X_L}{X_U - X_L}\right)(T_U - T_L)$ Let $T_U - T_L$ $T = T_L + \left(\frac{X_T - X_L}{X_U - X_L}\right) N$

Method 02

From the first principle

$X_T = KT$ $X_L = KT_L, X_U = KT_U$

Taking,

$X_T - X_L = K(T - T_L) - (i)$

$X_U - X_L = K(T - T_L) - (ii)$

Dividing equation (ii) by (i) and simplifying,

we get

$$T = T_L + \left(\frac{X_T - X_L}{X_U - X_L}\right)(T_U - T_L)$$

- Temperature in ℃ scale

  $T = 0℃, \quad X_L = X_0$

  $T_U = 100℃ \quad X_U = X_{100}$

$$T = 0 + \left[\frac{X_T - X_0}{X_{100} - X_0}\right] \times 100℃$$

- Temperature in °F scale

$$\boldsymbol{T} = \mathbf{32}°\text{F} + \left[\frac{X_T - X_0}{X_{212} - X_{32}}\right] \times 180°$$

Additional concept

$$T(℃)\left[\frac{X_T - X_0}{X_{100} - X_0}\right] \times 100℃$$

$$\frac{I}{100} = \frac{X_T - X_{ice}}{X_{stream} - X_{ice}}$$

Examples of thermometric property

1. Platinum resistance thermometer

$$T = \left[\frac{R_T - R_0}{R_{100} - R_0}\right] \times 100℃$$

2. Thermocouple thermometer

$$T = \left[\frac{E_T - E_0}{E_{100} - E_0}\right] \times 100℃$$

3. For constant volume gas thermometer $(P_T \propto T)$

$$T = \left[\frac{v_T - V_0}{v_{100} - v_0}\right] \times 100℃$$

4. Constant pressure gas thermometer $(v_T \propto T$

$$T = \left[\frac{P_T - P_0}{P_{100} - P_0}\right] \times 100℃$$

5. For the length of liquid column

$$T = \left[\frac{L_T - L_0}{v_{100} - v_0}\right] \times 100℃$$

6. The Ideal Gas Scale gives results that are identical to thermodynamic scale, which is quite independent of the properties of any individual substance. The thermometric property of the ideal gas scale is the product of pressure volume for a fixed mass of an Ideal gas. The Celsius temperature scale is given

$$T = [\frac{(PV)_T - (PV)_0}{(PV)_{100} - (PV)_0} \times 100\%$$

ii) The temperature scale on different thermometers (thermometric property) agree to each other when you measure the temperature on the fixed point.

Reason: **s**ince temperature scale on different thermometers obtained by using their fixed point

iii) On measuring temperature of the same body by using different thermometer show different readiness. Why?

> **Reason:** This is due to the variation of the thermometric properties with temperature on different thermometers are different from each other

7. FAULTY THERMOMETER

This is the thermometer that does not measure the actual values of temperature. This is due to the incorrect calibration of thermometer, non-uniform liquid in a tube and poor material used as a thermometer not to measure the actual temperature, the problem starts from wrong value of both lower and upper fixed point.

Actual temperature	Wrong temperature
100 ℃	0 ℃ upper fixed point
t	θ℃ intermediate
0 ℃	$-\theta$ L lower fixed point

$$\frac{c-0}{100} = \frac{\theta - (-\theta_L)}{n}$$

$$\frac{c}{100} = \frac{\theta + (\theta_L)}{n}$$

$$When\ C = t, \theta = \theta_l$$

$$\frac{t_1}{100} = \frac{\theta_1 - \theta_L}{n}$$

Solve for n

$$n = \frac{100}{t_1}(\theta_1 - \theta_L)$$

Now

$$\frac{c}{100} = \frac{\theta + (\theta_L)}{n}\ n = 100$$

$$\frac{100}{100}\ \frac{\theta + \theta_L}{n}$$

$$n = \theta + \theta_L$$

$$\theta = n - \theta_L = \frac{100}{t_1}(\theta_1 + \theta_L)_{\theta_L}$$

$$\theta = \frac{100}{t_1}(\theta_1 + \theta_L) - \theta_L$$

SOLVED EXAMPLE

TYPE B

Example 01.

Write an expression which calibrated a thermometric property X of read temperature in Celsius degree. Hence find the temperature of the system when pressure is 4.6 Pa. Given that the lower and upper fixed points of the pressure of the system are 1.5 Pa and 3.0Pa respectively

Solution

Temperature in °C $scale$

$$T(°C) = T = \left[\frac{X_T - X_0}{X_{100} - X_0}\right] \times 100°C$$

$$T = \left[\frac{P_T - P_0}{P_{100} - P_0}\right] \times 100°C$$

$$= \left[\frac{4.6 - 1.5}{3.0 - 1.5}\right] \times 100°C$$

Example 02

A liquid in the glass uses a liquid volume which varies with temperature according to the relationship

$$V_\theta = V_0\,(1 + a\theta + b\theta^2)$$

Where Vθ and V_0 are the volumes of the liquid at θ°C and 0°C respectively, while "a" and "b" are constants. If $a = b \times 10^3$; what will be the reading in glass when the actual temperature is 60°C?

Solution

$$V_\theta = V_0\,(1 + a\theta + b\theta^2)$$

At 100°C

$$V_{100} = V_0\,(1 + 100a + 10{,}00b)$$

$$V_{100} - V_0 = V_0\,(100a + 10{,}000b)$$

At 60°C

$$60°C\; V_{100} - V_0\,(60a + 3600b)$$

Temperature of the scale on this scale

$$T = \left[\frac{V_{60} - V_0}{V_{100} - V_0}\right] \times 100°C$$

$$= \left[\frac{V_O(60a + 3600b)}{V_0(100a + 10{,}000b)}\right] \times 100°C$$

$$T = 57.2°C$$

Example 03

The resistance R_θ of a coil of a wire at temperature θ on the Ideal - gas scale is given by

$$R_\theta = R_0[1 + \propto \theta + \beta\theta^2]$$

Where R_0 Is the resistance at 0°C

$$\propto = 4 \times 10^3 k^{-1}$$

$$\beta = -6.0 \times 10^{-7} k^{-2}$$

If the resistance of this coil of wire even used to define resistance temperature scale, what will be the difference between the temperature value assigned to an object by this scale and the temperature of 40°C indicate on the ideal gas equation assuming both scale both scale conceded at 0°C and 100°C

Solution

Given that $R_\theta = R_0[1 + \propto \theta + \beta\theta^2]\ at\ 100°C$

$$R_{100} - R_0 = R_0[100 + 10{,}000\beta]$$

$$R_{40} - R_0 = R_0[40 \propto + 1600\beta]$$

The temperature recorded on this scale

$$T = \left[\frac{R_T - R_0}{R_{100} - R_0}\right] \times 100℃$$

$$= \left[\frac{R_0(40 \propto +1600\beta)}{R_0(100 \propto +10{,}000\beta)}\right] \times 100℃$$

$$= \left[\frac{40 \times 4 \times 10^{-3} + 1600x - 6 \times 10^{-7}}{100 \times 4 \times 10^{-3} + 10{,}000x - 6 \times 10^{-7} -}\right]$$

$$\times 100℃$$

T=40.37℃

LET $\Delta T = TEMP.DIFFERENCE$

$$\Delta T = T - T_0 = 43.37 - 40$$

$$\Delta T = 0.37℃$$

Example 04

A constant mass of gas maintained at constant pressure has a volume of $200cm^3$ at the temperature of melting ice $273.2cm^3$ at the temperature of boiling point under standard atmospheric pressure and $525.1cm^3$ at the normal boiling point of Sulphur. A platinum resistance wire has a resistance of 2.0, 2.778Ω and 5.280Ω at the temperature.

Calculate the value of the boiling point of Sulphur given that two set of observation

Solution

for constant pressure gas thermometer

$$T = \left[\frac{V_T - V_0}{V_{100} - V_0}\right] \times 100℃$$

$$= \left[\frac{525.1 - 200}{273.2 - 200}\right] \times 100℃$$

$$T = 444.1$$

For platinum resistance thermometer

$$T = \left[\frac{R_T - R_0}{R_{100} - R_0}\right] \times 100℃$$

$$= \left[\frac{5.28 - 2.00}{2.77 - 2.00}\right] \times 100℃$$

$$T = 421.6℃$$

COMMENT OF THE RESULT

The temperature recorded the two thermometers are different. This is due to fact that the variation of volume of gas with temperature at constant pressure gas thermometer is quietly different from the variation of resistance with temperature on the platinum resistance thermometer.

Example 5 NECTA1999/P1

a) What do you understand by these terms?
   (i) Thermodynamic temperature scale
   (ii) Triple point of water
b) The resistance of wire at the temperature T(℃) measured on a gas scale is given by

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

What temperature will be on the platinum resistance thermometer indicate when temperature on the gas scale is 200℃ ? that a=3.8$\times 10^{-3}, b = -5.7 \times 10^{-7}$

Solution

a) refer to your notes

b) At 100℃

$R_{100} - R_0 = R_0[100a + 10{,}000b]at$

200℃

$R_{200} - R_0 = R_0[200a + 40{,}000b]$

Since

$$\theta = \left[\frac{R_{200} - R_0}{R_{100} - R_0}\right] \times 100℃$$

$$\theta = \left[\frac{R_0(200 \times 3.8 \times 10^3 + 40{,}000 \times 5.7 \times 10^{-7})}{R_0(100 \times 3.8 \times 3.8^{-3} + 10{,}000 \times 5.7 \times 10^{-7})}\right] \times 100℃$$

$\theta = 197℃$

Example 06

A given platinum has a resistance R_0 and R_{100} at the ice and stream point respectively

i) write an expression for the fundamental interval

ii) if the resistance R at unknown temperature θ ; write an expression for the value of θ.

iii) suppose the value of θ is now doubled, how will the new resistance be related with R and R_0.

Solution

i. $N = R_{100} - R_1$

ii. $\theta = \left[\frac{R-R_0}{R_{100}-R_0}\right] \times 100℃$

iii. $2\theta = \left[\frac{R_1-R_0}{R_{100}-R_0}\right] \times 100℃$

$R_1 = New\ resistance$

$$2\left[\frac{R - R_0}{R_{100} - R_0}\right] \times 100 = \left[\frac{R_1 - R_0}{R_{100} - R_0}\right] \times 100℃$$

$2R - R_0 = R_1 - R_0$

Example 07 NECTA 2017/P1/8 (c)

The value of the property X of a certain substance is given by

$x_\theta = X_0 + 0.5\theta + 2 \times 10^{-4}\theta^2$

Where θ is the temperature in degree Celsius. What would be the Celsius temperature defined by the property X which corresponds to a temperature of 50℃ on this gas thermometer scale (4marks)

Solution

Given

$x_\theta = X_0 + 0.5\theta + 2 \times 10^{-4}\theta^2$

$x_\theta - X_0 = 0.5\theta + 2 \times 10^{-4}\theta^2$

At 100℃

$x_{100} - X_0 = 0.5 \times 100 + 2 \times 10^{-4}100^2$

$x_{100} - X_0 = 52$

At 50℃

$x_{50} - X_0 = 0.5 \times 50 + 2 \times 10^{-4}(50)^2$

$x_{50} - X_0 = 25.5$

$$\theta = \left[\frac{x_{50} - X_0}{x_{100} - X_0}\right] \times 100℃$$

$$= \left[\frac{25.5}{52} \times 100℃\right]$$

$\theta = 49.04$ ℃

Example 08

a) A Celsius temperature scale may be defined in terms of thermometer property X by the following equation

$$\theta = \left[\frac{x - x_0}{x_{100} - x_0}\right] \times 100$$

Where x_0 is the value of the property at the ice point, x_{100} at the some intermediate temperature . If X is plotted against θ a straight line always result no matter what thermometer property is chosen, Explain this.

b) The value of the property X of a certain substance is given by $X_t = X_0 + 0.5t + 2 \times 10^{-4}t^2$, where t is the temperature in degree Celsius measured on a gas thermometer scale what would be the Celsius temperature scale defined by the property X which corresponds to a temperature of 50°C on this gas thermometer scale

Solution

a) Since there is equal increase in the property x with equal increase in the value of the temperature θ

b) Refer to the solution example 07

Example 09

a) Two thermometer are based on different properties but they are calibrated by using the same fixed points. To what extent are the thermometers like to agree when used to measure temperature:

b)

i) Near one of the fixed point?

ii) Mid way the two fixed point?

c) The resistance of a certain wire at Celsius temperature t measured on the Ideal gas scale is given by

$$R_t = R_0[1 + 4 \times 10^{-3}t^2]$$

Where R_0 is the resistance at o°C .what is the temperature on the resistance scale using this wire, when the temperature is 50°C on the ideal gas scale?

Solution

a)

i. Near a fixed point temperature will agree quite closely i.e. they shows the same readings.

ii. midway any different of the same body due to the difference variation of thermometer property with temperature.

b)

$Rt - Ro = Ro[4 \times 10^{-3}t + 10^5t^2$]at 100°C

$$R_{100} - R_0 = R_0[4 \times 10^{-3} \times 100 + 10^{-5} \times (100)^2]$$

$R_{100} - R_0 = 1.5R_0 - R_0 = 0.5R_0$ At 50°C

$$R_{50} - R_0 = 1.45R_0 - R_0 = 0.45R_0$$

$$T = \left[\frac{R_{50} - R_0}{R_{100} - R_0}\right] \times 100°C$$

$$= \left[\frac{0.45R_0}{0.50R_0}\right] \times 100°C$$

T = 90°C

Example 10 NECTA 2010 /P1/5(a)

i) Define thermal convection

ii) In a special type thermometer a fixed mass of gas has a volume of $100cm^3$ at pressure of 80.6 cmHg at the ice point and volume of $124cm^3$ and pressuer of 90 cm Hg at the stream point .Determine the temperature if its volume is 120 cm^3 and pressure of 85 cm Hg

iii) What values des the scale of this thermometer give for absolute zero

Solution

i) Refer to your notes

ii) Since

$$T = \left[\frac{(PV)_T - (PV)_0}{(PV)_{100} - (PV)_0}\right] \times 100°\text{C}$$

$$= \left[\frac{(120 \times 85) - (100 \times 81.6)}{(124 \times 90) - (100 \times 81.6)}\right] \times 100°\text{C}$$

$\mathbf{T = 68.0}$°C

At absolute zero temperature

$(PV)_T = 0$

$$T = \left[\frac{0 - (100 \times 81.6)}{(124 \times 90) - (100 \times 81.6)}\right] \times 100°\text{C}$$

T =-272°C

- **Example 11**

A thermometer has wrong calibration. It records the melting point of ice -5°C it reads 55°C instead of 50°C find the temperature of boiling point of water on the given scale

Solution

Let η Be number of division between upper fixed point θ_2 and lower fixed point θ_1

$$\frac{C}{100} = \frac{\theta_2 - \theta_1}{n}$$

In first case :$\theta_2 = -5°\text{C}, c = 0°\text{C} - 5 - \theta_1 = 0, \theta_1 = 5°\text{C}$

In second case $\theta_2 = 55°\text{C}, c = 50\ \frac{50}{100} = \frac{55-\theta}{n} = \frac{55-(-5)}{n}\ \frac{1}{2} = \frac{60}{n}, n = 120$

We know that boiling point of water is 100°C θ_2=?

$\frac{100}{100} = \frac{\theta_2-(-5)}{120}$

$\boldsymbol{\theta_2 = 115}$°C

Example 12 NECTA 2019/P1/7(a)

i) Why water is preferred as a cooling agent in many automobile engines? (2marks)

ii) A thermometer has wrong calibration as it reads the melting point of ice as -10°C . If it reads 40°C in a place where the temperature reads 30°C. Determine the boiling point of water on this scale (3marks)

Solution

i) Water has a high value of specific heat. It means a relatively small amount of water will absorb a large amount of heat for a correspondingly small temperature rise. Due to this water is very useful cooling agent in cooling system of automobile

Since

$$\frac{c}{100} = \frac{\theta + 10}{n}$$

$when\ c = 30℃, \theta = 40℃$

$$\frac{30}{100} = \frac{40 + 10}{n}$$

$$30n = 50{,}000 = n = \frac{50{,}000}{30} = \frac{500}{3}$$

If $c = 100℃,\ \theta?$

$$\frac{100}{100} = \frac{\theta + 10}{n}$$

$$n = \theta + 10$$

$$\theta = 10 - n = \frac{500}{3} - 10$$

$$\theta = 166.97 - 10, \theta = 156.67℃$$

Example 13

A faulty thermometer has its fixed point marked as 5° and 95°. The temperature of a body as measured by the faulty thermometer is 59°. Find the correct temperature of the body on Celsius scale.

Solution

If T_C is correct temperature on Celsius scale

$$\frac{T_C - 0}{100} = \frac{X - L.F.P}{U.F.P - L.F.P}$$

$$\frac{T_C}{100} = \frac{59 - 5}{95 - 5} = \frac{3}{5}$$

$$\boldsymbol{T_C = 60}$$

Example 14

When a thermometer is taken from the melting ice to a warm liquid, the mercury level rises to $\frac{2}{5}$ th of the distance between the lower and the upper fixed point. Find the temperature of liquid in ℃ and K.

Solution

Temperature of liquid

= $\frac{2}{5}$ of distance between L.F.P and U.F.P

$$\boldsymbol{T = \frac{2}{5} \times 100 = 40}℃$$

On Kelvin scale $T_K = 273.15 + 40$

$$T_K = 313.15K$$

Example 15

The ice and steam points of a certain thermometer are found to be 20cm apart. What temperature is recorded in degree Celsius when the length of the mercury thread is 5 cm above the ice point mark.

Solution

$100℃ \rightarrow 20cm$

$\theta \rightarrow 5cm$

$$\theta = \frac{5cm \times 100℃}{20cm}$$

$$\theta = 25℃$$

∴ **A length of 5cm represent 25**℃

CHARACTERISTICS OF A GOOD THERMOMETERS

1. Sensitivity (can appreciable change in the state of coordinate produced by small change in temperature).

2. Accurate in measurement of the state of coordinates.
3. Repeatability

TYPES OF THEMOMETERS

1. Thermocouple thermometer
2. Platinum resistance thermometer
3. Gas thermometer
4. Liquid thermometer
5. Pyrometer thermometer
6. Thermistor thermometer
7. Bimetal strip thermometer
8. Magnetic thermometer
9. Lactometer thermometer

1. Thermocouple thermometer

Is the kind of thermometer which record the temperature of the body due to the variation of e.m.f with the temperature i.e. $E_T \propto T$.

THERMOCOUPLE – is the device which converts heat energy into electrical energy.

MODE OF CONSTRUCTION

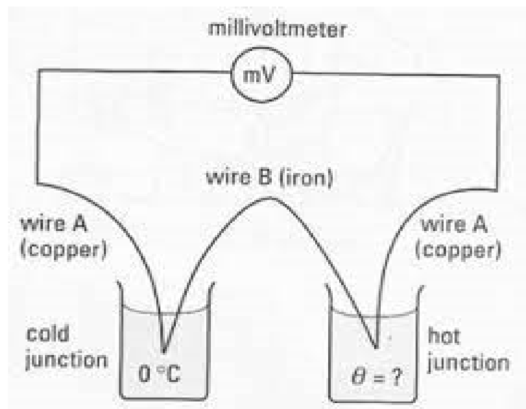
Thermocouples work on a principle called the see beck effect or thermoelectric effect.

If two different metals such Iron and Constantan wires are twisted together at junctions are joined in circuits and their junctions are kept at a different temperature, a small e.m.f develops between the junction. This effect is called thermoelectric or see beck effect.

SEEBECK EFFECT is the phenomena that happen in the circuit when the two different metals are joined together and small e.m.f (mV) develops within
junction due to the different of the temperature.

OR

Is the phenomenon of production of e.m.f in a thermocouple when its two junction are at different temperature diagram of the thermocouple.



THERMOELECTIC E.M.F - Is the e.m.f produced by a thermocouple when two different metals are joined and its junctions are maintained under the different temperature.

Conditions necessary for an e.m.f to appear between the junctions of thermocouple

i) The junctions must be kept at the different temperature.

ii) The junctions must be made of two different metals. The cold junction is immersed on the bath contains ice water mixture (ice -point) while the other junction is placed on the bath contain hot liquid whose temperature is θ.

The registered e.m.f, $E\theta$ is noted and the temperature of the liquid is defined by

$$\theta = \left(\frac{E\theta - E_0}{E_{100} - E_0}\right) \times 100$$

Where E_0, E_{100} and E_θ

Thermoelectric e.m.f at 0°C respectively if $E_0 = 0$

If no temperature different between the cold and the hot junction

$$\theta = \frac{E_\theta}{E_{100}} \times 100°\text{C}$$

The variation of e.m.f with temperature on thermocouple given by

E = A$\theta + B\theta^2$

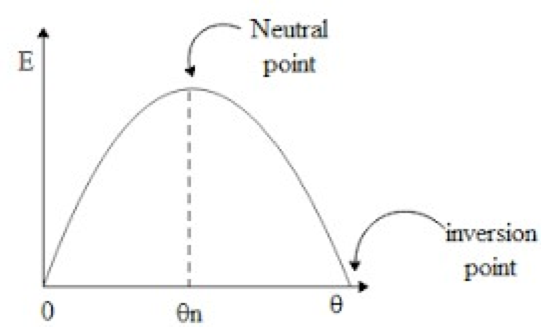
E = A$\theta - B\theta^2$

E = $\propto \theta + {}^1\!/_2\, \beta\theta^2$

E = A$\pm B\theta \pm C\theta^2$

Where A, B, C, β and $\propto$ are constant to a given thermometer

GRAPH OF E.M.F AGAINST e.m.f TEMPERATURE



The equation $E = A\theta + B\theta^2$

Is a parabola symmetrical about the mental temperature if the cold junction is kept at 0°C and the temperature of hot junction θ is gradually increased it found that the thermoelectric e.m.f E, first increases until attains decreases to become zero again .

The temperature at which the thermoelectric e.m.f is maximum is called Neutral temperature and the temperature at which thermoelectric e.m.f change its direction is the inversion temperature.

1. REFERENCE TEMPERATURE (θ_C)

   Is the temperature at which the cold junction is maintained and can be maintained with the temperature of the hot junction.
2. NEUTRAL TEMPERATURE (θ_n)

   Is the temperature which is corresponding to the maximum thermocouple.
3. INVERSION TEMPERATURE $(\theta)_1$

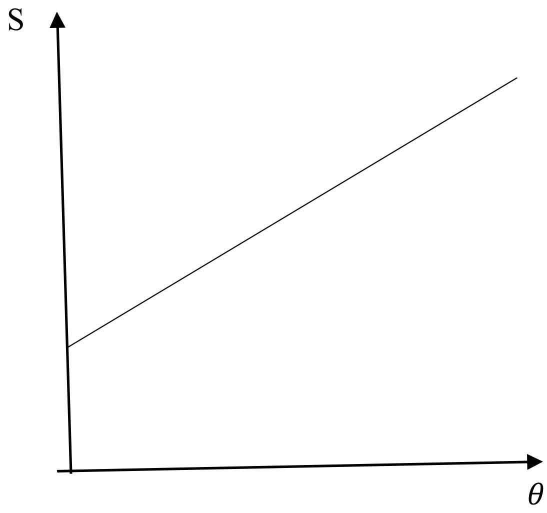
   Is the temperature in which thermos - e.m.f of the thermocouple can be reversed and become equal to zero.
4. THE THERMOELECTRIC POWERS

   The rate of change of thermoelectric e.m.f with temperature is called thermoelectric power or see beck coefficient

$$s = \frac{dE}{d\theta} = \frac{d}{d\theta}\,[A\theta + B\theta^2]$$

$$S = \frac{dE}{d\theta} = a + 2B\theta$$

Graph of S against temperature θ



If $S = \frac{dE}{d\theta} = 0$, then the corresponding temperature is known as Neutral temperature.

Expression of θn and $\theta 1$ from the graph

$\theta_n = \frac{\theta_c + \theta_1}{2}$

also $\theta_1 = 2\theta_n - \theta_c$

Special case:

If

$\theta_c = 0°C\ \theta_n = \frac{\theta_1}{2},$

$\theta_1 = 2\theta_n$

Expression of θ_1 *and* θ_n from the given equation

i) Let $E = A\theta + B\theta^2$

Expression of θ_n

$$\frac{dE}{d\theta} = \frac{d}{d\theta}[A\theta + B\theta^2] = A + 2B\theta$$

When $\frac{dE}{d\theta} = 0,\ \theta = \theta_n$

$0 = A + 2B\theta_n \theta_n = \frac{-A}{2B}$

Expression θ_I

$When\ E = 0, \theta = \theta 1\ 0 = A\theta_1 + B\theta_1^2 \theta_1 = \frac{-A}{B}$

special case : $if\ \theta_c \neq 0,$

$then\ \theta_1 = \frac{\theta_n + \theta_c}{2}$

ii) Let $E = \propto \theta - \frac{1}{2}\beta\theta^2\ \frac{dE}{d\theta} = \propto - \beta\theta$

When $\frac{dE}{d\theta} = 0, \theta = \theta_n$

$\theta_n = \frac{\propto}{\beta}$

Also $\theta_1 = 2\theta_n = \frac{2\propto}{\beta}$

5. MAXIMUM THERMO - E.M.F

Is the maximum value of the thermoelectric e.m.f of the thermocouple corresponding to the neutral temperature.

$Emax = A\theta_n + B\theta_n^2$

THEMOELECTRIC SERIES

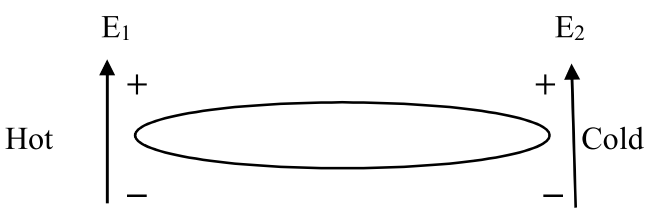
Is a series of metal arranged so that if a thermocouple in formed from any two metals, then current will flow from metal earlier in the series to a metal later the series through the junction.

According to see beck, the series is as shown below Sb, Fe, Zn, Ag, Au, Cr, Sn, Pb, Cu, Co, Ni, Bi.

Note that: The greater the separation of the metals forming the thermocouple in the series, the greater is the thermo - e.m.f produced for a given temperature, difference between the two junctions.

THE ORIGIN OF THE THERMO E.M.F

If two different metals are in contact and forming the junctions, more free electrons diffuse from one metal (especially having low work function) to the metal having higher work function. Therefore, one metal becomes positively charged becomes negatively charged. The process continuously until equilibrium is attained.

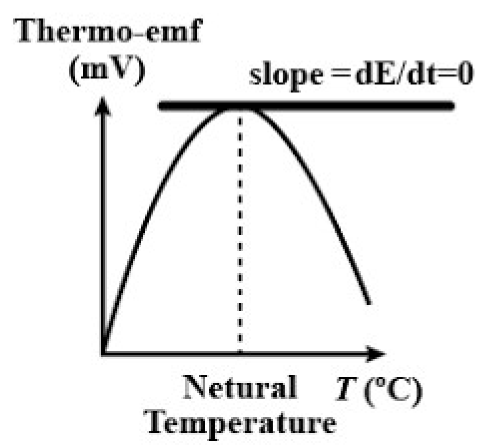


If the two junctions are maintained at the same temperature, the e.m.f $E_1 and\ E_2$ are equal in magnitude having opposite sign .Then, they cancel each other and net thermo e.m.f is equal to zero.

If the two junctions are maintained at different temperature, then $E_1 > E_2$. Therefore, there is net thermo e.m.f.

Additional concepts of the thermocouple thermometer

1. The temperature of the hot junction at which the thermo e.m.f is zero and changes its polarity is known as inversion temperature.
   - If the temperature is increased beyond θ_n, the direction of thermo e.m.f is reversed. Why?
     Reasons: This is due to the fact that the number densities and rate of the diffusion of electrons in the two metal used are reversed.
   - The see beck effect is the perfectly reversible if the hot and cold junctions are interchanged, the direction of the current is reversed.
2. The inversion temperature can be depending on the following factor:
   i. The temperature of the cold junction
   ii. The nature of metals forming the junctions
   - Neutral temperature can be depending only on nature of materials forming the junctions of thermocouple but is independent on the temperature of the cold junction.
3. Thermocouple is not used to measure temperature above its neutral temperature because the same value of thermo electric e.m.f is corresponding to the two different values of the temperatures. This lead to the wrong measurement.



4. Thermocouple is used to measure temperature below their neutral temperature

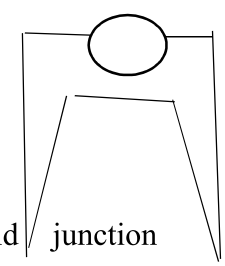
Reason: since there is linearly approximately of the variation of the thermo e.m.f with the temperature.

5. Thermocouple does not used to measure temperature close to is neutral temperature.

   Reason: At the neutral temperature .,$\frac{dE}{d\theta} = 0$ thus close to the neutral temp. the variation of e.m.f with temperature is very small, consequently the thermocouple is insensitive in this region.

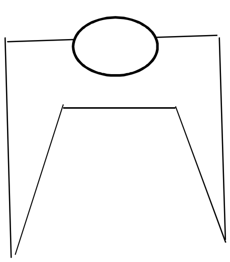
6. Effect of rise of temperature of cold junction when the temperature of hot junction is kept constant. This tend to reduce the value of the thermo e.m.f due to the decrease of temperature difference between cold junction and hot junction.

Before temperature rise of cold junction



Cold junction Hot junction

After rise of temperature of cold junction.



Assume that e.m.f varies linearly with temperature difference.

$E \propto \Delta\theta, E = K\Delta\theta$

K= Constant of proportionality represent pod per Kelvin (mVK^{-1})

$E_1 = K\Delta\theta$

Taking ,$\frac{E_1}{E} = \frac{K\Delta\theta_1}{K\Delta\theta} = \frac{\Delta\theta_1}{\Delta\theta}$

$E_1 = E = \frac{\Delta\theta_1}{\Delta\theta}\ Now\ \Delta E = E - E_1$

$\Delta E = E\left[\frac{\Delta\theta - \Delta\theta_1}{\Delta\theta}\right]$

$Fraction\ change\ i\ e.m.f$

$\frac{\Delta E}{E} = \left[\frac{\Delta\theta - \Delta\theta_1}{\Delta\theta}\right] \times 100\%$

ERROR ON THE MEASUREMENT OF TEMPERATURE ON THE THERMOCOUPLE

If the e.m.f on the thermocouple incurred with an error of K% and the thermo e.m.f of the temperature ,θ. You are required to obtain an expression of the temperature range incurred by thermocouple for the given percentage.

$\frac{K}{100} = \frac{B\theta^2}{A\theta + B\theta^2}$

$100B\theta^2 = KA\theta + BK\theta^2\theta = \frac{KA}{B(100 - K)}$

ADVANTAGES OF THERMOCOUPLE

1. Have very wide range (-200°C to 1500°C).
2. Due to the electrical nature, measurement of temperature is more accurate by this method.
3. Can be used to measure rapidly changing temperatures. This is because it has very small heat capacity.

4. As the junction is very small, thus it absorbs only a small amount of heat from the object. Consequently, the temperature of the object does not change.

DISADVANTAGE OF THERMOCOUPLE

1. The reference temperature has to be kept constant all the time of measurement.
2. Requires very sensitive meter to measure the very small voltage generated.
3. The thermo-e.m.f – temperature relation is non-linear.
4. Thermocouples are not direct reading thermometers.
5. For the measurement of temperature of different ranges, different thermocouples have to be used.

USES OF THERMOCOUPLE THERMOMETER

1. Widely used in Industries for measuring rapid changing temperature and temperature at a point.
2. Used for detection of radiation detection. A combination of a large number of thermocouples in series is called thermopile is used to detect heat radiation.
3. Power generation see beck effect can be used for power generation in remote areas especially for radio receivers.

SOLVED EXAMPLE TYPE C

Example 01 NECTA2008/P1/5

a)

i. What is meant by "reference temperature" as applied to thermocouple?

ii. The E.M.F (in mV) In a lead -IRON thermocouple one junction of which is at 0°C is given by $v = 1784t - 2.4t^2$ where t is the temperature of hot .unction in°C. Calculate the temperature

iii. When a particular temperature is measured on the scale based on different properties it has different numerical value on each scale except at certain points. Explain why and state at what points the value agree.

Solution

a)

i. See your notes

ii. since,

$$v = 1784t - 2.4t^2 \frac{dv}{dt} = 1784 - 4.8t$$

$$when \frac{dv}{dt} = 0\ t = t_n 0 = 1784 - 2.4t_n$$

$$t_n = 371.67°C$$

iii. the numerical value of the temperature of the body measured by different thermometric properties is different due to the different variation of the thermometric properties with the temperature .The numerical value agree at their fixed point i.e. ice -point (0°C) and the steam point (100°C).

Example 02

a) Define the following terms

   i) Thermo electrics power

   ii) Neutral temperature

b) In a certain thermocouple ,the thermo e.m.f E is given by $E = \propto \theta + \frac{-1}{20}\ UV/°C2$

   Find:

i) Find neutral temperature

ii) The inversion temperature

   Solution

a) See your notes

b) (i) $E = \propto \theta + \frac{1}{2}\beta\theta^2$

$$\frac{dE}{d\theta} = \propto + \beta\theta$$

At neutral temperature,

$\frac{dE}{dE} = 0\ 0 = \propto + \beta\theta_n$

$$\theta_n = \frac{-10}{\frac{-1}{20}}$$

$\theta_n = 200°C$

ii) $\theta 1 = 20\theta_n = 400°C$

Example 3 NECTA 1990/P2/8

a) Explain the term thermoelectric e.m.f and reference temperature as applied in the thermocouple.

b) The e.m.f generated in a thermocouple at temperature difference between two junction is given by E = $a\theta + \ B\theta^2$. Calculate the output of the thermocouple when temperature of its junction difference temperature is 54°C

[Answer: 2469.96 Mv]

Example 04 (DSM MORK -2007FV)

i) Define the term neutral temperature

ii) The e.m.f E of a thermocouple at temperature θ is given by $E = 1 + a\theta - b\theta^2$. The emf is found to be 4.5mV at 100°C and 10.5mV at 200°C . calculate the value of "a" and "b" and use therm to calculate neutral and inversion temperature

Solution

i) Refer to your notes

ii) Given that

$$E = 1 + a\theta - b\theta^2$$

$$E - 1 = a\theta - b\theta^2$$

$$4.5 - 1 = 100a - 10000b$$

$$3.5 = 100a - 10000b \ldots\ldots..(1)$$

Also

$$10.5 - 1 = 200a - 40000b$$

On solving simultaneously equation (1) and (2)

a=0.0225$\times\ mV\ °C - 2\ b = -1.25 \times 10^2 mV°C^{-2}$

Let $\theta_n\ neutral\ temperature$

$$\frac{dE}{d\theta} = a - 2b\theta_n$$

$$\theta_n = \frac{a}{2b} = \frac{0.0225}{-1.25 \times 10^{-4}}$$

$$\theta_1 invertion\ temperature\ \theta_n = 2\theta_n = 2 \times -90$$

$$\boldsymbol{\theta_n = -180}°C$$

Example 5 NECTA 2000/2004/P1

A copper constantan thermocouple with its cold junction at 0°C had an e.m.f junction at 4.28mV with junction 100°C , the e.m.f becomes 9.29mV when the temperature is 200°C . If the thermo e.m.f is related to the temperature θ by equation $E = AB\theta^2$

a) Calculate the value of A and B.
b) Up to what temperature range may E be assumed proportional to θ without an error of 1% more than that percentage.

Solution

a) Since $E = A\theta + B\theta^2$

$4.28 = 100A + 10000B - - - (i)$

$9.29 = 200A + 40000B - - - (2)$

On solving simultaneously equation (1) and (2)

$$A = 39.15 \times 10^{-3} mV \text{ °C}^{-1} = \frac{39.15Uv}{k}$$

$$B = 0.0365 \times 10^{-3} = 0.0365 mV/K^2$$

b) $\frac{B\theta^2}{A\theta+B\theta^2} = \frac{1}{100}$

$$100B\theta^2 = A\theta + BB\theta^2$$

$$\theta = \frac{A}{99B} = \frac{39.15}{99 \times 0.0365}$$

$$\theta = 10.83k$$

Example 06

A temperature scale is defined using the e.m.f developed by the thermocouple as the thermoelectric property. If at zero scale the e.m.f is 2mV. What is the temperature on such scale when the e.m.f is 2.7 mV?

Solution

$$\theta = \left(\frac{E\theta - E_0}{E_{100} + E_0}\right) \times 100$$

$$= \left(\frac{2.7 - 2}{3.2 - 2}\right) \times 100\text{°C } \theta$$

$$= 58.33\text{°C}$$

Example 7

The e.m.f obtained on chromate constantan is 6.32mV at 100°C and 24.91mV at 600°C. If the emf; E is related to the Celsius scale by $E = A\theta + B\theta^2$. Show that the temperature when e.m.f ; E is 16.4 mV is approximately 300°C.

Solution

Since $E = A\theta + B\theta^2 6.32 = 100A + 10000B - (1)$

$24.91 = 600A + 36000B - (2)$

On solving simultaneously equation (1) and (2)

$$A = 6.754 \times \frac{10^{-2} mV}{\text{°C}}$$

$$B = 4.3410^{-5} mV/\text{°C}^2$$

Now

$$16.4 = 6.756 \times 10^{-2} 4.34 \times 10^{-5} \theta^2$$

On solving the value of θ quad radically

$$\theta = 1255\text{°C } or \ 301.16\text{°C}$$

$$\therefore when\ E = 16.4mV, \theta = 300\text{°C}(approx)$$

Example 08

a) A thermometer registers its own temperature. Discuss.

b) (i)state two conditions for an e.m.f to appear between the junction of thermocouple.

(ii)the e.m.f E (mV)of a certain thermocouple is found to vary with temperature, t according to the relation. $E = 40t - \frac{t^2}{20}$

Where t is the temperature of the hot junction, the cold junction kept at 0°C. What is the neutral temperature of the thermocouple?

Solution

a) Interestingly enough, a thermometer registers its own temperature, when thermometer is in thermal contact with an object, the temperature of which are wish to measure energy will flow between the two until their temperature are equal and thermal equilibrium is established. If we then know the temperature of the thermometer, we also know the temperature of object.

$$E = 40t - \frac{t^2}{20}$$

$$= \frac{dE}{dt} = 40t - \frac{t^2}{20}$$

$$when\ \frac{dE}{dt} = 0,$$

$$t = tn\ 0 = 40t - \frac{t^2}{20}$$

$$\boldsymbol{t_n} = \mathbf{400}℃$$

Example 9 NECTA 2013/P1/5

a) Name the temperature of a thermocouple at which the thermo
   i) e.m.f change its sing
   ii) Electric e.m.f becomes

b) A nichrome - constantan thermocouple gives about 70μV for each 1°C difference in temperature between the junctions. If 100 such thermocouples are made into a thermocouple, What voltage is produced when the junctions are at temperature 20°C and 240°C.

Solution

a)
   i. inversion temperature
   ii. neutral temperature

b) (ii) $a = \frac{70\mu v}{℃}, n = 100$

$$\theta_1 = 20℃, \theta_2 = 240℃$$

Assume that thermo e.m.f varies linear with temperature

$$E = an(\theta_2 - \theta_1) = 70 \times 100(240 - 20)$$

$$E = 154000UV = 1.54\ Volt$$

Example 10

An e.m.f of 1V is generated when the temperature difference between the hot and cold junction of a thermocouple is 100k. Assuming that the cold junction is heated by 20k, determine the percentage change in the thermo e.m.f.

Solution

Assume that thermo e.m.f varies linearly with temp. difference

$$E \propto \Delta\theta, E = K\Delta\theta$$

$$E_1 = K\Delta\theta_1 \frac{E_1}{E} = \frac{K\Delta\theta_1}{\theta\Delta}$$

$$\frac{\Delta E}{E} = \frac{E - E_1}{E} = \frac{\Delta\theta - \Delta\theta_1}{\Delta\theta}$$

Percentage change in e.m.f

$$\frac{\Delta E}{E} \times 100\ \% = \frac{E - E_1}{E} \times 100\ \%$$

$$= \frac{\Delta\theta - \Delta\theta_1\ \times 100\ \%}{\Delta\theta}$$

$\boldsymbol{Answer}$: $\mathbf{20}$ %

Example 11

a)

i. why is thermocouple not used to measure temperature above its neutral temperature?

ii. Why is thermocouple not used to measure temperature close to its neutral temperature?

b)

i. In a given thermocouple, the temperature of the cold junction is 20°C while the neutral temperature is 270°C. Find the inversion temperature.

ii. The thermo e.m.f of a copper-constantan thermocouple and the temperature of the hot junction (with the cold junction at 0°C) are found to satisfy approximately the following relation

E = $a\theta + \frac{1}{2}b\theta^2$ where E is in μv, θ is in °C , $a = 4.1\ \mu vv°\mathrm{C}^{-1}$ and b=0.041 of hot junction when the thermoelectric e.m.f is measured to be 5.5mV?

Solution

i) Refer to your notes

(i) $\theta_1 = 2\theta_n - \theta_c = 2 \times 270 - 20$

$\theta_1 = 520°\mathrm{C}$

ii) $5.5 \times 10^{-3} = 4.1\theta + \frac{1}{2}\ (0.041)\theta^2$

On solving quadratic equation

$\theta = 200°\mathrm{C}$

Example 12

a)

i. Up to what factors do temperature of inversion depend?

ii. Up to what factors do neutral temperature depend?

b)

i. Why is lead used as a reference metal in thermoelectricity?

ii. For a Copper-Iron and a Chrome-Alumel thermocouple, the plots between thermoelectric e.m.f and temperature, θ of the hot junction (when the cold junction is at 0°C) are found to satisfy approximately the parabolic equation

iii. $v = \propto \theta + \frac{1}{2}\beta\theta^2$.

With $\propto = 14uV°\mathrm{C}^{-1}, \beta = -0.04uV°\mathrm{C}^{-2}$

For Cu-Fe thermocouple and $\propto = 41\mu V°\mathrm{C}^{-1}$, $\beta = 0.002\mu V°\mathrm{C}^{-2}$.

Which of the two thermocouples would use to measure temperature range of 500°C to 600°C?

Solution

a) Refer to your notes

b)

i. The thermo e.m.f of lead is almost zero. Therefore, is used as a reference metal to express thermo e.m.f or thermoelectric constants.

ii. $v = \propto \theta + \frac{1}{2}\beta\theta^2 \ \frac{dV}{d\theta} = \propto + \beta\theta$

$$when\ \frac{dV}{d\theta} = 0, \theta = \theta_n$$

$$\theta_n = \frac{\propto}{\beta}$$

. For Copper-Iron thermocouple

$$\theta_n = \frac{-14}{-0.04} = 350℃$$

For Chrome - Alumel thermocouple

$$\theta_n = \frac{-41}{0.02} = -20500℃$$

When $E = E_{max},\ \ \theta = \theta_n$

The suitable thermocouple used to measure the given temperature range, the neutral temperature $\theta_n < 0$ for maximum value of function.

∴The suitable thermocouple used to measure the given temperature range is Chrome -Alumel thermocouple since -20500℃ $<$ 0℃

Example 13

a)

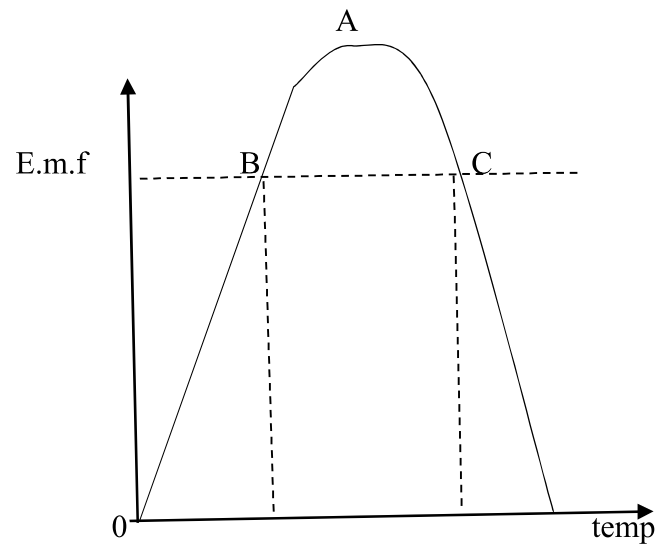
i. Is see beck effect reversible? Why is Sb-Bi thermocouple preferred?

ii. The thermo e.m.f is very small why?

b)

i. The graph of thermo e.m.f against different in junction temperature is a parabola. Which part of this graph is used for the measurement of temperature. Why?

ii. The cold junction of a thermocouple is maintained at 10°C. No thermo e.m.f is developed when hot junction is maintained at



220°C. Calculate the neutral temperature

Solution

a)

i. Yes, see beck effect is the reversible if the cold and hot junctions are interchanged, the direction of thermo e.m.f and current also are changed or reversed. For a given temperature difference, Sb-Bi thermo couple gives largest e.m.f compared to all thermocouples Sb is the last member of thermo electric series.

ii. The thermo e.m.f depend upon the junction potential difference. The rate of change of the potential difference with temperature is very small. This is because the change in free electrons density due to variation in temperature is small.

b)

i. the region 0A is used for temperature measurement. As it can be seen from the graph, the thermo e.m.f is the same for point B and C but their temperatures are different, So the region below the neutral temperature is used for the measurement of temperature.

ii. $\theta_n = \frac{\theta_c + \theta_1}{2} = \frac{10+2}{2}$ $\theta_n = 115°\mathrm{C}$

Example 14

A thermocouple is constructed of gold and Iron whose thermoelectric power are

2.8 + 0.01θ and 17.5 - 0.08θ microvolts per °C. Find

i. Neutral temperature
ii. The maximum e.m.f obtained with this thermocouple

Solution

(i) Thermoelectric power of gold -Iron thermocouple

$$p = \frac{dE}{d\theta} = \frac{d}{d\theta}[E_1 - E_2]$$

$$= \left(\frac{dE}{d\theta}\right)_{gold} - \left(\frac{dE}{d\theta}\right)_{Irin}$$

$$= (2.8 + 0.01\theta) - (17.5 - 0.048\theta)$$

$$\frac{dE}{d\theta} = 14.7 + 0.05\theta$$

$$\theta_n = 253.4°\mathrm{C}$$

ii) $\frac{dE}{d\theta} = p, dE = Pd\theta$

$$E\ max = \int_0^{\theta_n} Pd\theta$$

$$= \int_0^{253.4} (-14.7 + 0.058\theta)d\theta$$

$$\boldsymbol{E\ max = -1863\ \mu V}$$

EXAMPLE 15 NECTA 2014/P1/8b

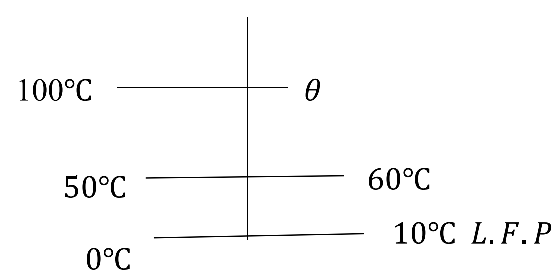
i) What is meant by temperature of inversion.

ii) A thermometer was wrongly calibrated as it reads the melting point of ice as $-10°\mathrm{C}$ and reading a temperature of 60°C in place of 50°C. What would be the temperature of boiling point of water on this scale?

Solution

i) Refer to your note

ii)



$$\frac{C-0}{100}=\frac{\theta-(-10)}{n}$$

$$\frac{C}{100}=\frac{\theta+10}{n}$$

When c = 50 , θ = 60℃

$$\frac{50}{100}=\frac{60+10}{n}$$

N = 140

When c = 100 ℃, $\theta = ?$

$$\frac{100}{100}=\frac{\theta+10}{140}$$

$$\theta+10 = 140$$

$$\boldsymbol{\theta} = \mathbf{130}℃$$

Example 16

a. The resistance of element of platinum thermometer 2.00Ω at the ice point and 2.73Ω at the steam point.

i) What temperature on the platinum scale could correspond to the resistance of 8.34Ω?

ii) Measured temperature correspond on the constant pressure gas scale, the same temperature corresponds to a value of 1020 ℃. Explain discrepancy.

(b) One junction of a thermocouple is place in melting ice while the other is inserted in to a bath whose temperature is measured by high temperature mercury in glass thermometer is T ℃. The following reading were obtained

T(℃)	0	100	200	300	400	500
E(mV)	0	0.64	1.44	2.32	3.25	4.32

By graphical method, find

i. The temperature on the thermocouple scale corresponds to 380℃ on Hg -in -glass scale.

ii. The temperature on Hg -in – glass corresponds to 250 ℃ on thermocouple.

Solution

a)

i. $\theta = \left[\frac{R_\theta - R_0}{R_{100}-R_0}\right] \times 100℃$

$$= \left[\frac{8.34-2.00}{2.73-2.00}\right] \times 100℃$$

$$\theta = 868.6℃$$

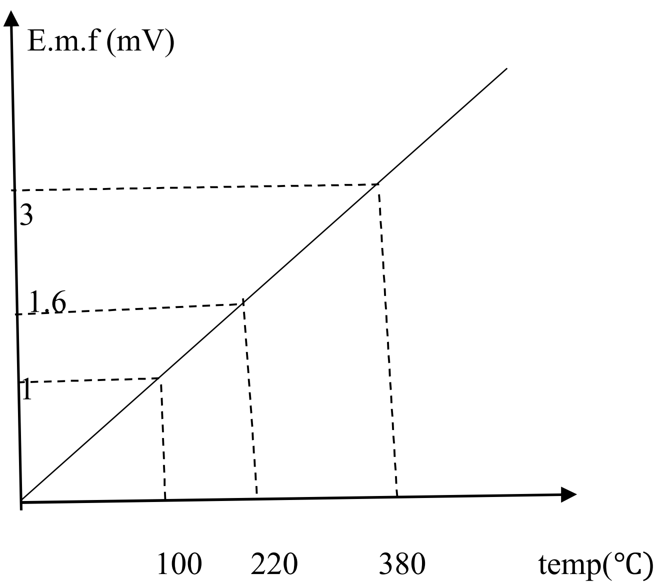
ii. Gas scale :1020℃

Gas scale :868.6℃

The two thermometer does not read the same degree of hotness because the variation of platinum resistance with temperature is different from the variation of volume of fixed mass of a gas kept at constant pressure with the temperature.

b.

GRAPH OF EMF AGAINST TEMPERATURE



i.

Hg-in-glass (T°C)	Thermocouple (θ°C)
0 °C	0°C
100°C	100°C
380°C	θ= ?

Example 17

The emf of Cu-Fe thermocouple varies with the temperature of the hot junction, the cold junction being at 10 °C as $E\theta(uV) = 14\theta - 0.2\theta^2$. Determine the neutral temperature and inversion temperature.

Solution

$$E\theta = 14\theta - 0.02\theta^2$$

$$\frac{dE}{d\theta} = 14 - 0.04\theta \ when$$

$$\frac{dE}{d\theta} = 0, \theta = \theta_n$$

$$\theta_n = \frac{14}{0.04} = 350°\text{C}$$

$$\theta_n = 350°\text{C}$$

Now $\theta_1 = 2\theta_n - \theta_c = 2 \times 350 - 10$

$$\theta_1 = 690°\text{C}$$

Example 18

a) The temperature of inversion of thermocouple is 610°C and the neutral temperature is 310°C. What is the temperature of cold junction?

b) Near the room temperature, the thermo e.m.f of a copper-constantan thermocouple is 40μ v/ °C. A galvanometer of 100Ω resistance capable of detecting currents as low as 10^{-6}A is used. What is the smallest temperature difference that can be detected?

Solution

a) $\theta_c = 2\theta_n - \theta_I$

$= 2 \times 310 - 610$

$\theta_c = 10°\text{C}$

b) Small e.m.f detected

$E = IR$

$E = 10^{-6} \times 100 = 100uV$

$1°C \rightarrow 40uV$

$\theta? \rightarrow 100uV$

$\theta = 2.5°C$

ASSIGNMENT 02

1. The temperature of cold junction of a thermocouple is $0°C$ and the temperature of hot junction is $\theta°C$ .The thermo e.m.f is given by $E = 16\theta - 0.04\theta^2$ In μV.

   Find

   i) The neutral temperature.

   ii) The inversion temperature.

   Answers: (i) 200°C (ii) 400°C

2. The e.m.f of the thermocouple is given by

$$E(mV) = 1.4 \times 10^{-2}$$
$$-2 \times 10^{-5}\theta^2$$

Where θ is the temperature in Celsius scale . Calculate

i) The maximum e.m.f.

ii) The inversion temperature

iii) The neutral temperature

iv) Thermoelectric power a temperature

Answers:

(i)3.45mvV (ii)700°C

(iii)350°C (iv) $6 \times 10^{-3} mV$ °C^{-1}

3. The thermo e.m.f of a thermocouple varies with temperature θ of the hot junction (cold junction at 0°C) as $E = a\theta + b\theta^2 uV$, where a and b are constants of the thermocouple. At temperature 20°C and 240°C the emf generated by this thermocouple are 850 μV and 9580 μV respectively. Find

i) The values of constant a and b.

ii) The neutral temperature

Answers:

(i) a =42.8 μV°C^{-1} and b = -00.012 μV°C^{-2}

(ii)1783°C

4.(a) How e.m.f is obtained in a circuit of thermocouple?

b)The e.m.f of lead -Iron thermocouple subjected to a temperature difference θ is given by

$E \times 10^6 (mV) = 1.670 - 0.015\theta^2$

i) Neutral temperature

ii) Inversion temperature

iii) Maximum value e.m.f.

iv) The temperature at which e.m.f is 4 mV.

5.

a) Explain what is meant by a scale corresponding to 45°C on platinum scale of thermocouple with one junction at the ice and the other at the steam point the temperature θ of thermistor.

b) θ°C = temperature on the thermocouple scale.

T(°C)= Temperature on the thermistor scale.

The following reading of the e.m.f of the thermocouple and the resistance R of the thermistor were obtained.

E (mV)	-0.8	+0.2	+1.3	+3.0	+5.6
R X $10^4\Omega$	5.6	5.2	4.7	4.2	3.6

The values of E were measured with one junction at the ice point.

i) Convent the e.m.f E to values of temperature.

ii) Plot a graph of $\log_{10} R$ Against $\frac{1000}{\theta+273}$

iii) Use your graph to find the resistance of the thermistor at temperature of 0°C, 50°C and 100°C and the thermocouple scale defined in the usual way. What temperature would it read at the temperature which 50°C on the thermocouple scale ?

2. ELECTRICAL RESISTANCE THERMOMETER

Is the thermometer which record the temperature of the body due to the variation of the resistance of a wire with temperature. The following are the factors which can be considered on choice of wire /metal used in electrical resistance thermometer:

i) The wire chosen should have high temperature so that a small changing in temperature causes measurable change in resistance.

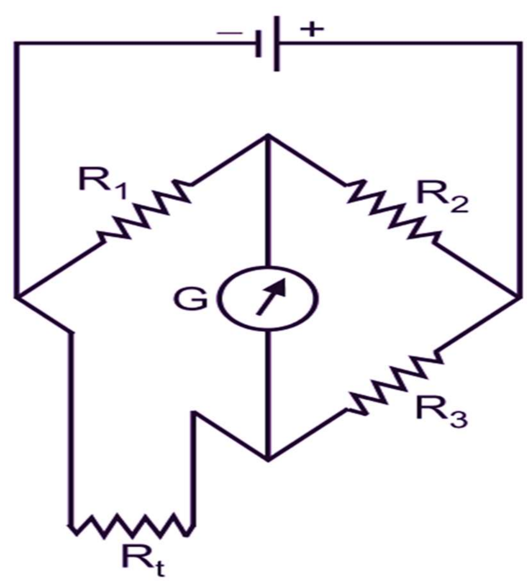
ii) Have high melting point (1773°C) to ensure that the wire will stand over high temperature.

iii) The resistance of a wire should vary linearly with temperature.

The metal of choice is platinum since have above characteristics. Sometime electrical resistance thermometer is known platinum **resistance thermometer**.

PRINCIPLE OPERATION

Platinum resistance thermometer consists four resistors which are arranged in the form of wheat stone bridge circuit. The coil of thermometer is connected in one arm of the bridge and at a balanced point for a given temperature is obtained



At the balanced point.

R_1

$R_T = R_1 R_3 / R_2$

Temperature scale on the resistance thermometer is given

$$T = \left(\frac{R_T - R_0}{R_{100} - R_0}\right) \times 100°\text{C}$$

Where $R_0,\ R_{100}\ and\ R_T$ are resistances at 0°C, 100°C and T(°C) resistance

Variation of resistance with temperature

Temperature coefficient of resistance - Is defined as the fractional change of the resistance per unit rise in temperature.

$$\propto = \frac{1}{R_0}\frac{dR}{d\theta}$$

$$dR = R_T - R_0\ , d\theta = T - T_0 \propto$$

$$= \frac{1}{R_0}.\frac{(R_T - R_0)}{(T - T_0)}$$

$$R_T = R_0[1 + \propto (T - T_0)]$$

Generally

$$R_T = R_0[1 + \propto T + \beta T^2]$$

$\propto\ and\ \beta\ are\ constant$

$\propto = 3.8 \times 10^{-3}\text{°C}^{-1}$

$for\ the\ platinum\ wire$

$ans\ R_T = R_0[1 + \propto T]$

$R_T = (R_{0\propto})T + R_0$

$y = m \times + c$

ADVANTAGE OF RESISTANCE THERMOMETER

1. Have very wide temperature range.
2. Best type of thermometer for measuring small steady differences of temperature.
3. The most accurate thermometer in the range 0f 13.8k to 904k
4. Have high accuracy of measurement.
5. Have small size and fast respond.

DISADVANTAGE OF RESTANCE THERMOMETER

1. High cost
2. Requires additional equipment such as bridge circuit, power supplied.
3. Have large in size than the thermocouple.
4. Have large heat capacity.
5. It is slow in action compared to thermocouple.
6. Uses of material of low thermal conductivity is sheath.

Uses

It is best thermometer for small steady temperature

Note that

This kind of thermometer is not suitable for everything temperature due to (4) point and (6) above

3. **LIQUID THEMOMETER**

Is the kind of thermometer which record the temperature of the body due to variation volume or length of the liquid column with the temperature.

THEMOMETRIC LIQUIDS

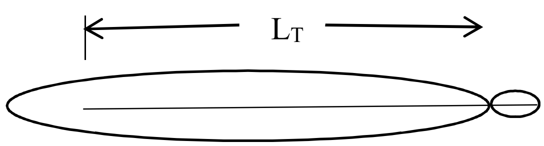
Those liquids whose volume or length of the liquid column varies linearly with temperature. Example: mercury and alcohol

Variation of volume of the liquid with temperature

$v_T = V_0[1 + aT + bT^2]$

Where "a" and "b" are constants and v_0 volume of liquid at 0°C since a $\gg b$ then

$$V_T = V_0[1 + at]$$



Temperature scale

$$T = \left[\frac{V_T - V_0}{V_{100} - V_0}\right] \times 100°C$$

$$T = \left[\frac{L_T - L_0}{L_{100} - L_0}\right] \times 100°C$$

COMPARISON OF MERCURY AND ALCOHOL AS THERMOMETRIC LIQUIDS

MERCURY

Reasons for using mercury as thermometric liquid:

1. Mercury is opaque and thus easily seen.
2. It is good conductor of heat so it shows the temperature of the body quickly.
3. It does not wet the wall of the glass tube.
4. Mercury have low specific heat capacity. It absorbs very little heat from the body whose temperature is to be measured.
5. It has uniform coefficient of expansion over a wide temperature range (-39°C to 357°C)

ALCOHOL

1. It wet the glass-concave meniscus.
2. Heat conduction is poor.
3. Transparent, must be used as dye.
4. Alcohol is more sensitive to temperature change than mercury but its expansion is very non-linear.
5. Have temperature range start from -114.9°C to 150°C

The sensitivity of liquid in glass can be increased by

1. Narrowing the liquid stem (narrow bore). Thus small temperature change causes a large rise in liquid in the tube.
2. Increasing the surface area of the bulb. This allows absorption of more heat for a small temperature change and then more expansion of the liquid
3. Using the bulb with thin wall. This allows faster conduction of heat from the object whose

temperature is to be measured to the mercury inside the bulb.

4. The space above the mercury in stem is evacuated. This provides free expansion for mercury.

ADVANTAGE OF LIQUID THERMOMETER

1. Gives direct reading.
2. It is simple, cheap and portable.
3. It is quick and easy to use

DISADVANTAGE OF LIQUID THERMOMETER

1. It is easy to get lost.
2. Has limited range on reading temperature [234-630K]
3. Not very accurate.
4. It has an error due to the bulb change when temperature changes.
5. Non – uniform of the bore of capillary.

USES

1. Used to measure the temperature of human body (clinical thermometer)
2. Used to measure temperature of hot liquid in the laboratory.

4. **GAS THERMOMETER**

Is the kind of the thermometer which records temperature of the body due to the variation of the pressure or volume of the gas with temperature.

TYPES OF GAS THERMOMETER

(i) Constant pressure gas thermometer

(ii) Constant volume gas thermometer

CONSTANT PRESSURE GAS THERMOMETER

Is the kind of gas thermometer which record temperature of the body due to the variation of volume of gas with temperature when pressure of gas is kept constant.

$V_T \propto T$

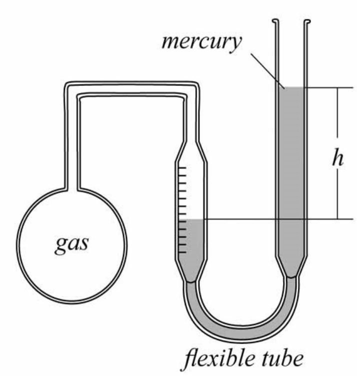
$V_T = V_0[1+\propto T]$

$T(°C) = \left[\frac{V_T - V_0}{V_{100} - V_0}\right] \times 100°C$

Where v_0, v_{100} *and* v_T are the volume of gas at 0°C ,100°C and T(°C) respectively.

CONSTANT VOLUME GAS THERMOMETER

Is the kind of gas thermometer which record to the variation of pressure of the gas with temperature when volume is kept constant.



It consists three bulbs B1, B2, and B3 which are made up by the glass materials. The bulbs are connected by rubber capillary tube. The bulb B1 contains dry air which can be immersed on hot liquid in order to measure the temperature on hot liquid in order to measure the temperature of hot liquid. The bulb B2 and B3 contain mercury in which the end of B3 is open to the atmospheric pressure. The air / gas filled in B1 is at the pressure greater than that of atmospheric pressure.

Theory

When the bulb B1 Is inserted in the bath contains hot liquid, then the difference in mercury level between the bulb B2 and B3 are noted. On accounting atmospheric pressure

$$p_T = P_a + h_T$$

At ice point : $P_0 = P_a + h_a$

At steam point : $P_{100} = P_a + h_{100}$

It follows that the temperature of the gas, T is defined by

$$T = \left(\frac{P_T - P_0}{P_{100} - P_0}\right) \times 100\text{°C}$$

OR

$$T = \left[\frac{h_T - h_0}{h_{100} - h_0}\right] 100\text{°C}$$

The variation of the pressure of the gas which temperature is given by

$$P_T = P_0(1 + \propto T)$$

Where P_0 is the pressure at 0°C and $\propto$ is the coefficient of increase of the gas at constant volume and has experimental value of $\frac{1}{273.15}$

.**ADVANTAGES OF GAS THERMOMETER**

1. It can measure a wide range of temperature (270°C to 1500°C)
2. The expansion of the gas is very large so gas thermometer are sensitive.
3. It is very accurate.
4. Gases are obtained in pure form.
5. Its reading are in close agreement with those in kelvin scale. So this thermometer is the standard by which others temperature scale are calibrated.

DISADVANTAGE OF GAS THERMOMETER

1. It is bulk or large in size and it is inconvenient on use.
2. It is slow to respond and not direct reading.
3. Air is not an ideal gas.
4. It demands much skill.
5. It is difficult to measure rapidly varying temperature because the bulb is large and have large thermal capacity.

Note that:

(i) A gas thermometer is 'SELDOM' used for temperature measurement in the laboratory measurement in the laboratory due to following reasons:

1. It is slow to respond.
2. The readings are not direct.
3. It is bulky and inconvenient on use.
4. Demanding much skills and time.

ADVANTAGES OF GAS THERMOMETER OVER LIQUID THERMOMETERS

1. Gases expand much more (about 20 times) than liquid for the same rise of temperature, so they are more sensitive.
2. The expansion of gases is regular over wide range of temperature
3. The thermal capacity of gases are low compared to the liquid, so even the small change of temperature can be noted accurately.
4. Gases can be obtained in pure form.
5. Gas thermometer can be used for wide range of temperature.
6. Gases are light and density is low compared to the liquid.
7. Different gases have identical scales because the volume and temperature coefficients of all gases are nearly equal.
8. The temperature measured with a gas thermometer and with s thermodynamics scale agree with each other.

USES OF GAS THERMOMETER

Used as standard temperature scale to obtain the scales of the thermometers.

5. **PYROMETR THERMOMETER**

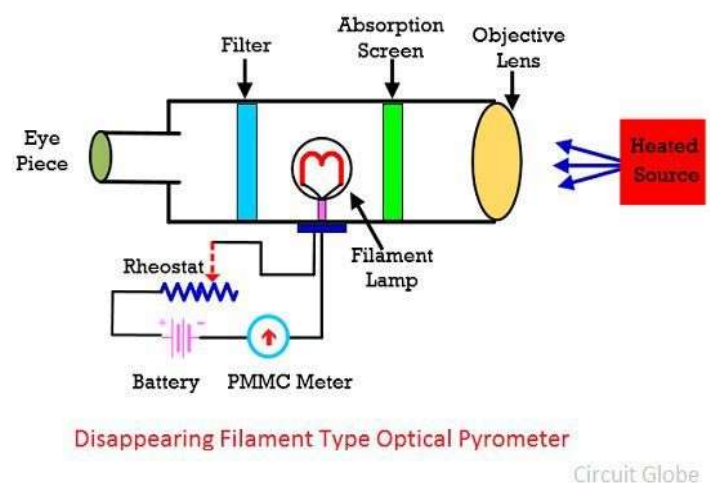
   Is the kind of thermometer which used to measure the temperature of very hot objects. The property used is quality of radiation emitted by the hot objects.

TYPES OF PYROMETERS

1. Total radiation pyrometers which respond to the total radiation from the hot body.
2. Optical pyrometers which respond only to the visible light.

OPTICAL PYROMETER

Optical pyrometers are also referred to as disappearing filament thermometers.



Disappearing Filament Type Optical Pyrometer

PRINCIPLE OF OPERATION

The temperature of the lamp, L is adjusted until the image of the filament cannot be distinguished from the back ground. At this point, the radiation of hot object and the light emitted by the lamp L, have the same wave length and therefore are at the same temperature.

TOTAL RADIATION PYROMETER	OPTICAL PYROMETER
It responds to both visible and invisible radiation.	It responds to visible radiations only.
It can be used for lower temperature than the optical pyrometer.	It can be used up to 1500, the temperature at which it is convenient to run a lamp.
It can be used with continuous recording instrument.	It cannot be used with continuous recording instrument.
It is a direct reading and need no setting by the observer.	The observer must adjust the current to match the color of the radiation from hot object.

$I_T \propto T$

$$T(°C) = \left[\frac{I_T - I_0}{I_{100} - I_0}\right] \times 100°C$$

Where I_0, I_{100} and I_T are currents at 0°C , 100°C and T(°C) respectively.

ADVANTAGE

1. Can be used to measure very high temperature.
2. Have very wide temperature range.
3. No contact with hot object.
4. It is portable.

DISADVANTAGE

1. Not direct reading, not highly accurate.
2. It affects the health of person.
3. It is cumbersome.
4. Reading above 1760 K are calculated from plank's. radiation laws.

SOLVING EXAMPLE TYPE D

1. **NECTA 1998/P1/6**

a) Define the thermodynamics temperature.

b) The resistance of platinum resistance thermometer is 1.20Ω when measuring a Kelvin.

Solution

a) Refer to your notes.

b) $T = \left(\frac{R_T}{R_{TR}}\right) \times 273.16$

$$K = \frac{1.2}{1.0} \times 273.16K$$

$$T = 327.79K$$

In Celsius scale

$$t = T - 273.15$$

$$= 327.76.15$$

$$t = 54.642°C$$

2. **NECTA 1995/P1/16**

a) What are the essential steps in order to establish a temperature scale?

b) The resistance R_θ of the particular resistance thermometer at Celsius temperature measured by constant volume gas thermometer is given by

$$R_\theta = 50 + 0.17\theta + 3 \times 10^{-4}\theta^2$$

Calculate the temperature on scale of resistance thermometer which correspond to a temperature of 60°C ?

Solution

a) Refer to your notes.

b)

$R_\theta = 50 + 0.17\theta + 3 \times 10^{-4}\theta^2$

At 0°C: $R_0 = 50\Omega$

At 60°C :

$R_{60} = 50 + 0.17 \times 60 + 3 \times 10^{-4 \times 3600}$

$R_{60} = 61.28\Omega$

At 100°C

$R_{100} = 5 = +0.17 \times 100 + 3 \times 10^{-4} \times 10^4$

$$\theta = \left[\frac{R_{60} - R_0}{R_{100} - R_0}\right] \times 100°\text{C}$$

$$\left[\frac{61.28 - 50}{70 - 50}\right] \times 100°\text{C}$$

$\boldsymbol{\theta = 56.40}$°C

3. The electrical resistance in ohm of a certain thermometer varies with temperature according to the approximate law

$R_T = R_0[1 + 5 \times 10^{-3}(T - T_0)]$

The resistance is 101.6Ω at the triple point of water and 165.5Ω at the normal (600.5k) melting point of lead (600.5k). What is the temperature when the resistance is 123.4Ω? Given triple point of water as 273.16k.

Solution

Given : $R_T = R_0[1 + 5 \times 10^{-3}(T - T_0)]$

$101.6 = R_0[1 + 5 \times 10^{-3}(273.16 - T_0)] - (1)$

$165.5 = R_0[1 + 5 \times 10^{-3}(600.5 - T_0)] - (2)$

$$\frac{101.6}{165.5} = \frac{R_0[1 + 5 \times 10^{-3}(600.5 - T_0)]}{R_0[1 + 5 \times 10^{-3}(273.16 - T_0)]}$$

On solving, $T_0 = -46K$.

$$R_0 = \frac{101.6}{1 + 5 \times 10^{-3}(273.16 - \ -46)}$$

$R_0 = 39.14\Omega$

$R_T = 123.4\Omega,$

$T = ?\ 123.4 = 39.14$

$[1 + 5 \times 10^{-3}(T - -46)]$

On solving

$\boldsymbol{T = 384.6K}$

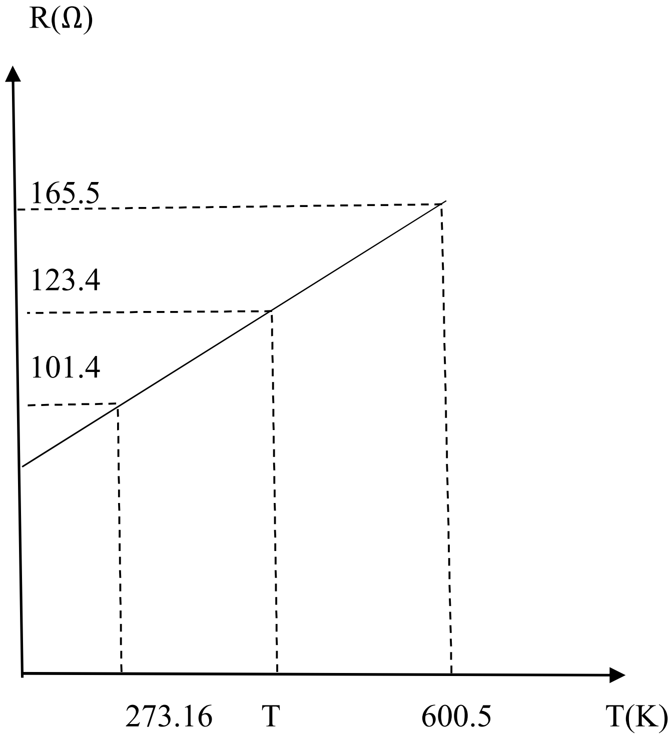
Alternatively, we can use the graphical method

By slop method

$$\frac{123.4 - 101.6}{t - 273.16} = \frac{165.5 - 101.6}{600.5 - 273.16}$$

On solving

$\boldsymbol{T = 384.83K}$



4. A silver wire has resistance of 2.5Ω at 0°C and temperature coefficient of 0.0037°C^{-1}. Find the temperature when its resistance becomes one and half time.

Solution

$$R_T = 2.5 \times \frac{3}{2} = \frac{7.5}{2} \quad R_T = R_0\,[1 + \propto T]$$

$$T = \frac{R_T - R_0}{\propto R_0} = \frac{\frac{7.2}{2} - 2.5}{2.5 \times 0.0037}$$

$\boldsymbol{T = 135.13}$°C

5. The resistance of a thermistor over a limited range of temperature is given by the equation.

$$R = \frac{C}{T - 203}$$

Where C is a constant and T is the absolute temperature. What would be the temperature on the centigrade scale of the thermistor at absolute temperature, T =300K?

Solution

Given that :

$$R = \frac{C}{T - 203}$$

At 0°C$(273K)$: $\quad R_0 = \frac{C}{273-2} \quad \frac{C}{70}$

At 100°C$(373K)$:

$$R_{100} = \frac{C}{373 - 203} = \frac{C}{170}$$

At $\theta(300K)$

$$R_{300} = \frac{C}{300 - 203} = \frac{C}{97}$$

$$Since\ \theta = \left[\frac{R_{300} - R_0}{R_{100} - R_0}\right] \times 100°\text{C}$$

$$= \left[\frac{\frac{C}{97} - \frac{C}{70}}{\frac{C}{170} - \frac{C}{70}}\right] \times 100°\text{C}$$

$\boldsymbol{\theta = 47.3}$°C $(\boldsymbol{Approx.})$

6. <u>NECTA2002/P1/5</u>

   a)

      i. Define thermodynamics temperature scale.

ii. How is thermodynamic temperature scale denoted and what it is S.I. unit?

iii. Explain why a gas thermometer is seldom used for temperature measurement in the laboratory?

b) Study the table below and answer the questions which follows:

Types of thermometer	Property	Value of property

i. Calculate the temperature of the room for each thermometer.

ii. Explain why the thermometer disagree in their values of room temperatures.

iii. What are the advantages of gas thermometers over liquid in glass thermometers?

Solution

a) Refer to your notes

b)

i. For gas thermometer

$$T = \left[\frac{P_T - P_0}{P_{100} - P_0}\right] \times 100℃$$

$$\left[\frac{895 - 760}{1240 - 760}\right] \times 100℃$$

$$\boldsymbol{T = 2.13}℃$$

For thermistor,

$$T = \left[\frac{I_T - I_0}{I_{100} - I_0}\right] \times 100℃$$

$$T = 27.57℃$$

ii. The variation of the pressure with temperature on the Gas thermometer is quietly different from the variation of current with temperature on thermistor thermometer.

iii. Refer to your notes

7. **<u>NECTA 2006 / P1 / 5</u>**

a)

i. Describe how mercury in glass thermometer could be made sensitive.

ii. A sensitive thermometer can be used to investigate the difference in temperature between the top and bottom of the waterfall. Calculate the temperature difference of the waterfall 50m high.

b)

i. Platinum resistance thermometer and constant volume gas thermometer are based on difference thermometric properties but they are calibrated using the same fixed points. To what extent are the thermometers likely to agree when used to measure temperature near the ice point and near the stream point?

ii. The resistance of the element of a platinum resistance thermometer is 2.0Ω at the ice and 2.73Ω at steam point. What temperature on the platinum resistance scale would correspond to resistance value of 8.34Ω and when measured on the gas scale the same temperature will correspond to a value of 1020 °C. Explain the discrepancy

solution

a)

i. refer to your notes
ii. Apply the law of conservation of energy

$$MC\Delta\theta = Mgh$$

$$\Delta\theta = \frac{gh}{c} = \frac{9.8 \times 50}{4200}$$

$$\Delta\theta = 0.116K$$

b) Refer to your notes

8. NECTA 1995 / P1 /7

Summarize the principle operation of the platinum resistance thermometer.

9. Roger, C7

Using the above data, which refer to the observations of a particular room temperature using two types of thermometer, calculate the room temperature on the scale of the resistance thermometer and on the scale of constant volume gas thermometer. Why these values differ slightly?

Solution

for resistance thermometer

$$\theta = \left[\frac{R_\theta - R_0}{R_{100} - R_0}\right] \times 100°C$$

$$\theta = \left[\frac{64.992 - 63}{75 - 63}\right] \times 100°C$$

for gas thermometer

$$\theta = \left[\frac{p_\theta - p_0}{p_{100} - p_0}\right] \times 100°C$$

$$\theta = \left[\frac{8.51 \times 10^6 - 8 \times 10^6}{1.1 - 10^7 - 8 \times 10^6}\right] \times 100°C$$

$$\mathbf{\theta = 17}°C$$

Comment:

The values differ because the variation of resistance with temperature on the resistance thermometer is quietly different from the variation of pressure with temperature on the gas thermometer.

10.

a) water is used as an effective coolant. Why?
b)

	Resistance of resistance thermometer	Pressure recorded by constant thermometer
Steam point 100°C	75.000Ω	1.10×10^7 Nm^{-2}
Ice point 0°C	63.000 Ω	8.00×10^6 Nm^{-2}
Room temp.	64.992 Ω	8.51×10^6 Nm^{-2}

i. Should a thermometer bulb have large heart capacity? Explain.

ii. The coefficient of volume expansion of mercury is $5.4\times 10^{-4}°C^{-1}$ what is the fractional change in its density for a 80°C rise in temperature.

solution

a) It is because the specific heat capacity of water is very high. When water is running over the hot part of the engine or machinery, absorbs a large amount of heat from it. Due to this, the temperature of the hot engine decreases.

b)

i. A thermometer bulb has small heat capacity in case, it has large thermal capacity, the temperature of the substance will get lowered due to the large amount of heat absorbed by the thermometer bulb.

ii.

$$V' = V(1+\propto \Delta T)$$

$$= V(1 + 5.4 \times 10^{-4} \times 80)$$

$$V' = 1.0432V$$

Initial density of Mercury

$$\rho = \frac{M}{V}$$

Final density, $\rho' = \frac{M}{V'} = \frac{M}{1.0432}$

Fractional charge in density of mercury

$$\frac{\rho - \rho'}{\rho} = \frac{\rho - 0.9586\varphi}{\rho}$$

$$\frac{\rho - \rho'}{\rho} = 0.0414$$

10.

a)

i. What is the cause of hotness of a body?

ii. A the 20°C , an uncalibrated thermometer reads 15° and at 80°C it reads 30°. Find the reading of un calibrated thermometer at fusion and boiling points of water.

solution

a)

i. The cause of hotness of a body is the kinetic energy of the molecules constituting the body

ii. The variation of many physical property of the substance with temperature forms the principle pf thermometer.

29. (a) What is meant by the absolute scale of temperature? Describe some form of thermometer which absolute temperature can be measure

(b) The apparent expansion of a liquid in glass is given by $V_t = V_0(1{+}\propto t + \beta t^2)$ where $\beta/\propto\ = -8 \times 10^{-5}°C$ and t is centigrade temperature measured by a constant volume air thermometer calculate the reading of liquid thermometer in the same enclosure reads 50 °C.

Solution

a) Absolute scale of temperature is a temperature scale which uses only one fixed point i.e triple point of water absolute scale is used as standard scale of temperature
A constant volume gas thermometer may be used to measure absolute temperature. The pressure of a gas in the triple point of water, Ptr. The pressure of a gas at temperature, T
$T = \left(\frac{P_t}{P_{TR}}\right) \times 273.16K$

b) $50.20°\text{C}$ (*student assignment*)

30. in the interval between 0 and 660°C ,a platinum resistance thermometer of definite specification is used for international practical temperature t is given by a formula for variation resistance with temperature

$R = R_0[1 + At + Bt^2]$

Where $R_0, A\ and\ B$ are constant determined by measurement at the ice point, the stream point and the Sulphur point (444.6°C)

(a) If $R = 10\Omega$ at the ice point, $13.946\,\Omega$ at the stream point and 24.817Ω at Sulphur point, find $R_0\ , A\ and\ B$
(b) Plot graph of R against t in the temperature range from 0 to 660°C

Solution

(a) Given:$R = R_0[1 + At + Bt^2]$

At $t = 0°\text{C}$

$10 = R_0[1 + A(0) + B(0)^2$

$R_0 = 10\Omega$

At $t = 100°\text{C}$

$13.1946 = 10[1 + 100A + 10{,}000B]$

$0.003946 = A + 100B - - - -(1)$

$Att = 444.6°\text{C}$

$24.817 = 10[1 + 444.6A + (444.6)^2B]$

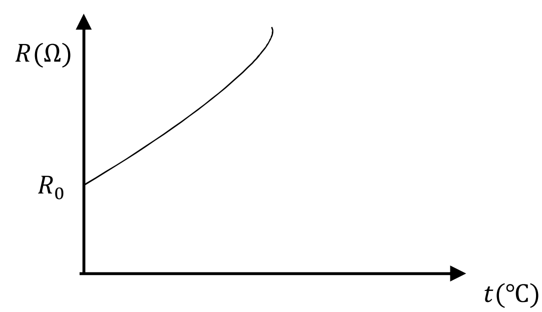
$1.4817 = 44.6A + 197669.16B - - - -(2)$

On solving equation (1) and (2)

$A = 4.124 \times 10^{-3}°\text{C}^{-2}$

$B = -1.780 \times 10^{-6}°\text{C}^{-1}$

The Graph R against t



31. (a) A particular constant volume gas thermometer register pressure of 1.937×10^4Pa at the triple point of water and 2.618×10^4Pa at the boiling point of a liquid. What is the boiling point of liquid according to this thermometer?

(b) The temperature measurement in point (a) above was repeated using the same thermometer but with different quantity of some gas. The readings on this occasion were 4.068×10^4Pa at the triple point of water and $5.503 \times 10^4 Pa$ at the boilinng point of liquid.

(i) What is the boiling point of the liquid according to this measurement?

(ii) Which of the two value is the better approximation to the ideal gas temperature and why

(iii) estimate the ideal gas temperature

Solution

$$a)\left(\frac{P_T}{P_{TR}}\right) \times 273.16K$$

$$= \left(\frac{2.618 \times 10^4}{1.937 \times 10^4}\right) \times 273.16$$

$$\boldsymbol{T = 369.20K}$$

$$b)(i)T = \left(\frac{5.503 \times 10^4}{4.068 \times 10^4}\right) \times 273.16$$

$$\boldsymbol{T = 369.52K}$$

(ii) The value 369.20K is the better approximation to ideal gas temperature because it is measured at low pressure and gases behaves more ideally at low pressure

(iii) The ideal gas temperature

$$T = limit \left(\frac{P_T}{P_f}\right) \times 273.16K$$

$$P_f \to 0$$

P_f= pressure at the triple point of water

When the pressure nearly doubles, the recorded temperature differs by 0.32K when the pressure at triple point reduces to nearly zero the ideal pressure will be 369.20-0.32=368.88k

32. The numerical value P and r of two thermometric properties P and R are observed at a number of fixed point. These numbers are related for all temperature by the equation $rr = \propto p\beta$ where $\propto$ and β are constants. Show that the property P and R are identical even if P and R do not vary linearly with temperature.

Solution

$$\theta_P = \left(\frac{P_\theta - P_0}{P_{100} - P_0}\right) \times 100℃ - - - - (1)$$

$$\theta_R = \left(\frac{r_\theta - r_0}{r_{100} - r_0}\right) \times 100℃$$

$$= \left[\frac{(\propto + P_\theta\beta) - (\propto + P_0\beta)}{(\propto + P_{100}\beta) - (\propto + P_0\beta)}\right] \times 100℃$$

$$\theta_R = \left(\frac{P_\theta - P_0}{P_{100} - P_0}\right) \times 100℃ - - (2)$$

$$(1) = (2)\theta_R = \theta_P$$

33. (a) Does a thermometer read its own temperature or the temperature of its surrounding?

(b) Suppose a mercury thermometer was put in a place shaded from the direct sunlight and reached a steady temperature. Another identical thermometer placed in direct sunlight would give a higher steady temperature. What are these two thermometer measuring? Explain making reference to the rate of emission and absorption of energy by the bulb. Why the readings are different

Solution

(a) A thermometer measures its own temperature which is equal to the temperature of its surrounding when are in the thermal equilibrium.

(b) The first thermometer measures the temperature of its surrounding and the second measure of radiant heat energy of the sun at the place.

the radiant are different because in the first instance the thermometer bulb absorbs energy from the surrounding only but in the second instance thee thermometer bulb absorbs energy from the surrounding as well as the coming directly from the sun

34. what type of the thermometer would you use to measure each of the following? in each case the reasons for your choice

(a) The boiling point of water on a mountain

(b) The temperature just after ignition in a cylinder of an internal combustion engine.

(c) The temperature of the filament of an electric lamp.

(d)The normal melting point of zinc

Solution

(a) Platinum resistance thermometer

It's very accurate than all other thermometer except gas thermometer. It is also respond quickly than gas thermometer

(b) Thermocouple thermometer

It responds quickly to varying temperature and also suitable to measure temperature at a point.

(c) Optical pyrometer

The is responds to visible radiations emitted by the filament. It is the only thermometer for measurement of high temperature that of the filament.

(d) Platinum resistance thermometer

Its accurate and it respond quickly compared to gas thermometer.

34. The thermometer property measurement for two different thermometers are shown in the table below. both thermometers are used to measure temperature, T of cooker oven

Thermometer	Thermometric property	T_{ice}	T_{steam}	T
Constant volume gas	P(mmHg)	760	1038.4	1396.8
Thermocouple	E(Mv)	0	4.4	10.164

(a) Find the value of T recorded by each thermometer.

(b) Comment on the values

(c) What action could you take the gas thermometer value closer to that of the thermodynamic scale?

Solution

(a) Constant volume gas thermometer

$$\theta = \left(\frac{P_\theta - P_0}{P_{100} - P_0}\right) \times 100℃$$

$$= \left[\frac{1396.8 - 760}{1038.4 - 760}\right] \times 100℃$$

$$\theta = 228.74℃$$

The temperature T in Kelvin

$$T = \theta + 273 = 501.74K$$

- Thermocouple thermometer

$$\theta = \left[\frac{E_\theta - E_0}{E_{100} - E_0}\right] \times 100℃$$

$= \left[\frac{10.164 - 0}{4.4 - 0}\right] \times 100°\text{C}$

$\theta = 231°\text{C}$

The temperature, T (K)

$T = 273 + 231$

$T = 504K$

(b) The difference is due to the fact that the variation of the e.m.f of thermocouple with temperature changes is different from the variation of the pressure with temperature on constant volume gas thermometer.

(c) To make gas thermometer value closer to the thermodynamic scale pressure of the gas reduced to low value where real gases behave as ideal gas at low pressure.

35. (a) Explain the purpose of the following feature of a clinical thermometer:

(i) A kick or constriction in the capillary tube.

(ii) a capillary of small cross -sectional area

(iii) a bulb of thin glass

(b)when the fixed point of Celsius thermometer are verified it read 0.5°C at the melting point of ice and 99.2 °C at the boiling point of water at normal pressure. What is the correct temperature when it read 15°C and at what temperature will it reading be exactly correct

Solution

(a) (i) A kink enable temperature to be read slowly and carefully. When the thermometer is taken from a hot body, the mercury does not contract in to the bulb again it breaks at the constriction the mercury above the constriction remain in the stem at the position it enables reading of temperature slowly. Before being used again, the thermometer is shaken to force the mercury back past the constriction in to the bulb.

(ii) To increase sensitivity. Small temperature change cause large change cause large change in the length of the mercury column.

(iii) Allow quick absorption of heat by glass to the mercury inside.

(b) Fundamental interval of correct thermometer =100 – 0 = 100°C fundamental interval of incorrect thermometer of

$= 99.2 - 0.5 = 98.7°\text{C}$

$now\ \Delta \times\propto \Delta$

$\theta \frac{98.9}{100}$

$= \frac{15 - 0.5}{\theta - 0}$

Let θ be the correct temperature

$$\frac{98.7}{100} = \frac{\theta - 0.5}{\theta - 0}$$

At $\theta = 38.5°\text{C}$

its reading will be exactly correct.

36. Two thermometer are constructed in some way except that one has a spherical bulb and the other has an elongate d cylindrical bulb. Which out of the two will respond quickly to temperature changes?

Solution

A thermometer with elongated cylindrical bulb will respond quickly to temperature change as its surface area is more than one with spherical bulb.

36. (a) Can you measure temperature up to 500°C with a mercury thermometer knowing that the mercury boiling at 357°C

(b) Why clinical thermometer should not be sterilized by boiling water.

Solution

(a) Yes ,we can measure temperature up to 500°C with mercury thermometer provided the space above mercury in thermometer is filled with nitrogen. This increases the boiling point of mercury
(b) Generally ,the range of clinical thermometer is from 97°F to 110°F and the boiling point of water is 212 °F if a clinical thermometer is sterilized by boiling water the capillary of thermometer will burst due to thermal expansion of mercury in the capillary tube of thermometer.

NOTE OF THERMOMETERS

1. A thermometer absorbs heat from a substance whose temperature it is measuring.
2. A thermometer record it is own temperature.
3. There is lag time before thermal equilibrium is reached between a thermometer and its surroundings.

4.Temp range	Thermometers
(i)-259°Cto660°C	Platinum resistance thermometer
(ii)660°Cto1064°C	Thermocouple
(iii)Above 1070°C	Radiation thermometers

ASSIGNMENT NO 3: TYPE D

38. A liquid in glass thermometer uses a liquid whose volume varies with temperature according to the relation

$V_\theta = V_0\,(1 + \propto \theta + \beta\theta^2)$,Where $\propto and\ \beta$ are constant. If $\propto = \beta \times 10^4$ what will be the temperature indicated o the liquid in this glass thermometer scale when that on that on the gas thermometer is 50°C.

[Answer :49.8°C]

39 .The e.m.f E obtained from a chrome -constantan thermocouple is $6.32mV\ at\ 100°C\ and\ 24.9mV\ at\ 600°C$. if E is related to the Celsius by

(a) Determine the neutral temperature and inversion temperature.
(b) What will be the value of temperature when the e.m.f ,$E = 16.4mV$

Answer

(a) $\theta_n = 778°C, \theta_i = 1556°C$
(b) 301°C

40. For a Cu-Fe thermocouple ,the cold junction is kept at 0°C the thermo emf E(Yv) vs given by $E =$

$a\theta + b\theta^2$ where A and B ae constant θ is the temperature on the ideal gas scale. If the numerical value of a and b are $14\mu V/°C$, and $-0.025\mu V/°C^2$ respectively.

(a) Determine the neutral and inversion temperature.

(b) What would be temperature θ on the ideal gas Celsius scale if the measured emf is $650\mu V$? What would be corresponding temperature θ on the thermocouple scale when $E = 650\mu V$?

Answer

(a) 280°C, 560°C

(b) 51°C ,56.5°C

<u>41. NECTA 2009/P1</u>

(a) The resistance and gas thermometer may show different value in measuring the temperature of the surrounding. Explain the reason behind.

(b) The electrical resistance in ohms of a certain thermometer varies with temperature according to the approximate law.

$R = R_0[1 + 5 \times 10^{-4}(T - T_0)]$

The resistance is 101.6Ω at the triple point of pure water and 165.5Ω at the normal melting point of lead (600.5K). Determine the temperature when the resistance is 123.4Ω

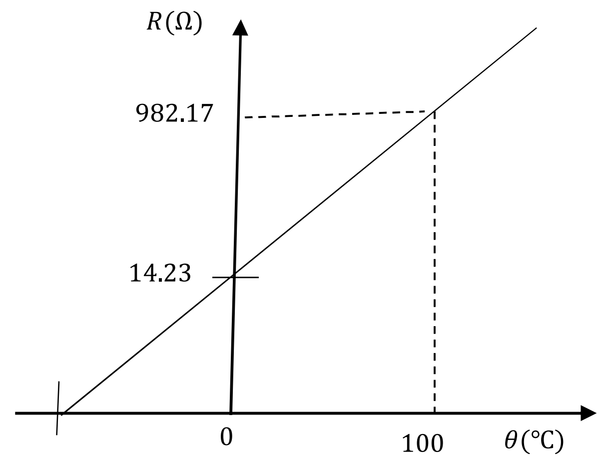
[Answer 384.7K]

42. EZEB 2009 /P1

(a) explant briefly essential characteristics which make a property of substance useful as thermometric property

(b) (i) what do you understand by the term "temperature coefficient of resistance "

(ii) the graph below show the variation of resistance $R\theta$ of a platinum wire thermometer against temperature , θ use the graph to calculate the temperature coefficient of resistance.



43. A certain platinum resistance thermometer as a resistance of 2.40Ω at 0°C ,3.34Ω at 100°C and 2.87Ω at an unknown temperature.

(a) Evaluate this temperature on the platinum resistance scale

(b) What value of resistance would be expected at -2°C on this scale

Answer (a) 50 °C (b) 2.38Ω

44. A certain resistance thermometer has a resistance of 5.00Ω at 0°C and its resistance at any other Celsius temperature is given by $R = R_0[1 + 4 \times 10^{-3}\theta]$

a) Calculate the resistance at 40°C

b) Calculate the temperature at which the resistance is 5.50Ω

[Answer (a) 5.8Ω (b) 25℃]

45. Explain what is meant by scale of temperature and how temperature is defined I term of specified property.

(b) when a particular temperature is measured on scale based on different properties it has a different numerical value on each scale except at a certain point. Explain why this so and state

(i) At what point the values agree and

(ii) what scale of temperature is used as a stand and [AP/TOMD]

Solution

(a) The scale of temperature is the scale that uses properties of some substance to measure temperature. The temperature based on property X is given by

$$\theta\left[\frac{X_\theta - X_0}{X_{100} - X_0}\right] \times 100℃$$

(b) The values differ because different properties vary differently with temperature change.

(i) The values agree at their fixed point i.e ice point and steam point

(ii) Thermodynamic temperature scale is used as a standard

46. the volume of a certain liquid at different temperature is given by

$V_t = V_0(1+\propto t + \beta t^2)$ where $\propto = 0.0011. \beta = -0.000002$ and t is the constant volume gas scale. If a thermometer ,graduated on the Celsius scale, is constructed using liquid ,what temperature will it record when $t = 40℃$

[Answer : 45.3℃]

47. EZEB 2012 /P1/5

a) (i) What is the difference between ideal gas temperature scale and thermodynamic temperature scale

(ii)What are the characteristics which make a property useful as a thermometric property?

b) The bulb of a constant volume air thermometer constant sufficient water to saturate the space up to 100℃ . if such a thermometer obeys the equation

$$P_\theta = P_0[1+\propto V\theta]$$

Where P_0 Is the pressure at melting point P_θ VS the pressure at a temperature $\theta \propto V$ is the volume coefficient. A 80℃ the pressure is 86Cm of mercury. Find the volume coefficient of air, provided the saturated vapor of water is 5.5Cm of mercury at 40℃ and 35.5Cm of mercury at 80℃

[Answer (b) 3.54$\times 10^{-3}K$]

48.The mercury level in a un calibrated mercury in a glass thermometer was the bulb when the thermometer was placed in melting ice and 18Cm from the bulb when it was placed in pure boiling water. Where will the mercury level be found at?

(a)25℃ (b) -5℃

[Answer (a) 6.0Cm from bulb

(b)1.2Cm from bulb]

49. The variation of the e.m.f of Cu-Fe thermocouple with temperature θ of the hot junction by keeping the cold junction at 10°C

Is given by $E = 14\theta - 0.02\theta^2$ where E Is in μV. Find the neutral temperature and temperature of inversion

[Answer : $\boldsymbol{\theta_n = 350}$°C, $\boldsymbol{\theta_1 = 690}$°C]

50. The e.m.f of capper -iron thermocouple ,one junction of which is kept 0°C is given by $E = a\theta + b\theta^2$ where $a = 14\mu V$°C^{-1} and $b = -0.02mV/$°C^2

(a) Find its neutral and inversion temperature.

(b) Can this thermocouple be used for the measurement of temperature in the range from 100°C to 500°C.

[Answer : (a)$\boldsymbol{\theta_n = 350}$°C , $\boldsymbol{\theta_1 = 700}$°C]

51. The thermo e.m.f in μV a copper – iron and a chrome -Alumel thermocouple whose cold junction at 0°C and hot junction at θ°C are given by $E = 14\theta - 0.02\theta^2\ and$

$E = 41\theta + 0.001\theta^2$

Respectively which of the two thermocouples may be used for measuring the temperature in the range of 400°C to 1000°C.

52. When the bulb of a constant volume gas thermometer is placed in melting ice ,the level of mercury in open tube is 5Cm below the level in closed bulb is 273°C ,the level in the open limb is 6Cm high. Calculate the barometer pressure

[Answer : $\boldsymbol{h = 75Cm\ of\ Hg}$]

53. the resistance of resistance thermometer at 19°C is 3.5Ω ad at 99°C it is 3.66Ω At what temperature will its resistance be 4.30Ω

[Answer: 419°C**]**

54. Two absolute scale A and B have triple point of water defined to be 200A and 300B what is the relation between $T_A and\ T_B$?

$T_{tr} = 273.16k$

[Answer $\boldsymbol{T_A = \frac{2}{3}T_B}$]

55. A thermometer with an arbitrary scale of equal part reads 1.6 in melting ice and 237.9 in water boiling under standard pressure. Find the centigrade temperature indicated by the reading 97.1 and 217 on this thermometer

[Answer: 36.95°C **,89.3**°C**]**

56. (a) at what temperature will the reading on the Fahrenheit scale be double that of Celsius scale?

(b) What is the value of absolute zero on Fahrenheit scale

[Answer: (a) 320°F **(b) -459.4**°F**.]**

57. Two thermometer, one Celsius and the other Fahrenheit are put in hot bath. The reading on Fahrenheit's thermometer is just three time the reading on Celsius thermometer. What is the temperature of bath?

[Answer: $\boldsymbol{\frac{80}{3}}$°C]

58.(a) why is generally not sensible to use thermo e.m.f as the physical property used to defined scale of temperature?

b) What is the absolute zero temperature

c) Explain why is platinum wire used in resistance thermometer?

59.(a) Why do we need two fixed point to set up a temperature scale?

(b) We cannot attain temperature below $-273.15°C$. why?

60. A thermometer vs type of thermometer that produces an e.m.f ,E that is related to the temperature θ by $E = a + b\theta$

Where a and b are constant depending on the metals involved used the following data to obtain values of a and b from a suitable graph

61. A platinum resistance thermometer used the change in resistance of a platinum wire to measure temperature. The resistance of the wire is given by

$$R = R_0[1 + a^\theta + b\theta^2]$$

Where θ is the temperature in °C. Given that $R = 10\Omega$ where $\theta = 0°C$, $R = 14\Omega$, $When\ \theta = 420°C$

(a) Calculate the R_0 ,a and b
(b) Sketch the graph of R against θ for $0°C < \theta < 500°C$.

Answer

a) $R_0 = 10\Omega, a = 4.209 \times 10^{-3}K^{-1}$ (b) $2..083 \times 10^6K^{-1}$

62. A mercury thermometer has no makings on its scale when placed in a flask of ice water the length of mercury column is 3.0cm. when placed in flask of boiling water the length of column is 30cm. what will be the length of column when placed in a flask of water at 40°C ? what will be the temperature of a flask of water when the column length is 15cm

[Answer : 13.2cm ,45.5°C**]**

63. The graph below show the variation in resistance of a piece of platinum wire with the temperature being measured on the idea gas scale. What is the Celsius temperature corresponding to a resistance of 17 Ω on

(a) The ideal gas?
(b) The platinum resistance scale?

Solution

(a) From the graph above ideal gas scale in Kelvin when $R = 17\Omega$

$T = 12.5 \times 4K/unit$

$T = 310K$

Temperature in °C scale

$t = (T - 273)$

$K = 310 - 273$

$t = 37°C$

b) From the graph above At $0°C(273k), R_0 = 16\Omega$

At $100°C(373k)$,

$R_{100} = 18\Omega$

$R_\theta = 17\Omega$

Since

$$\theta = \left[\frac{R_\theta - R_0}{R_{100} - R_0}\right] \times 100℃$$

$$= \left[\frac{17 - 16}{18 - 16}\right] \times 100℃$$

$$\theta = 50℃$$

64. On the graph ,line A shows how X varies with θ (follows the equation

$$\theta = \left[\frac{X - X_0}{X_{100} \times X_0}\right] \times 100℃$$

Line B show how a second thermometric property Q varies with θ ,the temperature measured on the X scale

(i) Describe in principle an experiment to obtain line B

(ii) If $\theta = 40℃$ recorded by an x- Scale thermometer ,what temperature would be recorded by a q-scale thermometer ?

(iii) At what two temperatures will the X and Q scale coincide?

(iv) The ideal gas scale of temperature is one based on the properties of an ideal gas. What is the particular virtue of this scale? Describe very briefly how reading on a such scale can be obtained using a thermometer containing a real gas

Solution

(i) The thermometric property Q I inserted say in a liquid and constant volume gas thermometer. The temperature of the liquid is raised and recorded by the gas thermometer while at some temperature and recorded by the gas thermometer while at some temperature and some recording the corresponding volume of Q is obtaining at the several pairs of Q and Q are obtained then the line B may be plotted

(ii) Temperature recorded by scale Q

$$Q = \left(\frac{Q - Q_0}{Q_{100} - Q_0}\right) \times 100℃$$

$$= \left(\frac{9.5 - 5}{25 - 5}\right) \times 100℃$$

$$Q = 23℃$$

(iii) The X and Q scales are coincided at the fixed point i.e. at ice point (0℃) and stream point (100℃)

(iv) The particular advantage of this scale is that all gases have some value of volume and pressure coefficient. Describe operation of a constant volume gas temperature

65. (a) How does neutral temperature and (ii) temperature of inversion of a thermocouple change if temperature of cold junction decrease?

(b) Calculate the thermo e.m.f of silver -iron thermocouple with junction at 0 ℃ and 80 ℃ .Given that $\propto = +13.31\ \mu V^{℃-1} and\ \beta = 0.038 \mu V^{℃-2}$ Also calculate the neutral temperature. Use the equation

$$E = \propto Q + \frac{1}{2}\beta Q^2$$

Solution

(a) (i) There will be no effect on neutral temperature because the neutral temperature does not depend upon the temperature of cold junction

(ii)The temperature of inversion of a thermocouple increases with the decrease in temperature of cold junction since

$\theta_I = 2\theta_n - \theta_c$

(b) $943.2\mu V, 350.3$℃

66.(a) What is see beck effect? Give one example. On what factors, magnitude of thermo e.m.f depend

(b) The thermo e.m.f of a Copper -iron thermocouple varies with the temperature of hot junction as

$E(\text{in}\mu\text{V}) = 110 - 0.02\theta^2$

Determine the neutral temperature if the cold junction is maintained at 0°C

Solution

(a) The generation of an electric current in a thermocouple by keeping its junction it different temperatures is called "see beck effect "
Example: when a thermocouple is formed of two wire of copper and iron the current flows from copper to iron the current flows from copper to iron though the hot junction
The magnitude of thermo e.m.f depend on it
    (i) The nature of two metal forming the thermocouple
    (ii) The temperature difference between two junction of the thermocouple.

(b) 275℃

67. What type thermometer would you use measure each of the following? in each case explain the reasons for your choice

(a) The boiling point of water on a mountain

(b) The temperature just after ignition in a cylinder of an internal combustion of engine.

(c) The temperature of the filament of an electric lamp

(d) The normal melting point of zinc

Solution

(a) <u>Platinum resistance thermometer</u>

It is very accurate than all other thermometer except gas thermometer. It is also responds quickly than gas thermometer.

(b) <u>Thermocouple thermometer</u>

It responds quickly to varying temperature it is also suitable to measure temperature at a point.

(c) <u>Optical thermometer</u>

This respond to visible radiation emitted by the filament. It is the only thermometer for measure high temperature like that of the filament

(d) platinum resistance thermometer

It is accurate and its respond quickly compared to gas thermometer.

68. The following table gives the resistance of a metal wire at the various temperature on mercury in glass thermometer

t(°C)	0	20	40	60	80	100
R(Ω)	10.0	30.38	10.82	11.24	11.60	12.00

Find

(a) The temperature on the metal resistance scale corresponding in glass scale

(b) As (a) but 70°C instead of 60°C

(c) The temperature on the mercury in glass scale corresponding to 19°C on metal resistance scale

(d) As (c) but 30°C instead of 19°C

Answer

(a) 62°C

(b) 71°C

(c) 20°C

(d) 30°C

69. The resistance of a given wire at various temperature on the constant volume gas scale are as under:

Temp (°C)	0	10	20	30	40	50	60	70	80	90	100
R (Ω)	5.0	5.08	5.16	5.23	5.31	5.4	5.5	5.61	5.73	5.86	6.00

Find

(a) The temperature on the resistance scale corresponding to 70 °C on the gas scale

(b) The temperature on the gas scale corresponding to 35°C on the resistance scale

Solution

(a) From the graph

$$R_0 = 5\Omega \ , R_{100} = 6.00 \ R_{75} = 5.67\Omega$$

$$\theta = \left(\frac{R_{75} - R_0}{R_{100} - R_0}\right) \times 100℃$$

$$\theta = \left(\frac{5.67 - 5}{6.00 - 5}\right) \times 100℃$$

$= 67℃$

(b) Since

$$35 = \left[\frac{R - 5}{6 - 5}\right] \times 100℃$$

$R = 5.35\Omega$

When $R = 5.35$, the corresponding temperature is 44°C from the graph

70. Why is water a very useful cooling agent

Solution

Water has a high value of specific heat. It means a relatively small amount of water will absorb amount of heat for corresponding $(Q = MC\Delta T)$ Small temperature rise because water is very useful cooling agent and is in the cooling system of automobiles and other engines. If a liquid of lower specific heat were used in cooling system, its temperature would rise higher for a comparable absorption of heat