**SENIOR FIVE TERM 2**

## TOPIC 3/7: THERMOMETRY

**Competency:** The learner investigates the mode of operation of different types of thermometers and their applications in the real world.

### Thermometry

This involves the study of thermometers as instruments used to measure temperature on the basis of certain physical thermometric properties which change with temperature and remains constant at constant temperature.

**A thermometric property** is a physical quantity which varies continuously, uniformly and linearly with temperature and remains constant at constant temperature.

### Scales of temperature

These are scales in which the measure of hotness or coldness of a body can be expressed .i.e. the measure of hotness or coldness of a particular body can be expressed in;

- Degrees centigrade ($^0$C) forming a Celsius scale of temperature.
- Kelvin (K) forming a thermodynamic scale of temperature.
- Degrees Fahrenheit ($^0$F) forming a Fahrenheit scale of temperature.

Convrsion os scales

If t$^0$C is temperature reading

- The thermodynamic scale is given by T= (t +273)K
- Fahrenheit scale temperature = $\left(\frac{9}{5}t + 32)\right) F$

Types of thermometers and thermometric property

| Type of thermometers | Thermometric property |
|---|---|
| Liquid in glass | Length of liquid column |
| Electrical resistance thermometer e.g. platinum resistance | Resistance of the platinum wire |
| Gas thermometer e.g. constant volume gas thermometer | Changes in pressure with temperature |
| Thermocouple | Induced e.m.f |
| Radiation pyrometer | radiation |

## Qualities of a good thermometric property

- Considerably vary for small changes in temperature.
- Vary over a wide range of temperature (both high and low)
- Vary linearly, uniformly and continuously with temperature
- Be accurately measurable over a wide range of temperature with a simple apparatus

**Related concepts**

(i) **Fixed point** is defined as constant temperature at which a physical state of pure water is expected to change at 760mmHg. Fixed points are basically two i.e. $0^0$C and $100^0$C.

(ii) **Lower fixed point ($T_0$)** is the temperature of pure melting ice at 760 mmHg. It is $0^0$C.

(iii) **Upper fixed point ($T_{100}$)** is the temperature of pure steam at 760mmHg. It is $100^0$ C.

(iv) **Triple point ($T_{tr}$)** is the temperature at which pure water pure steam and pure ice co – exist in equilibrium at 760mmHg. It is $0.16^0$ C or 273.16K.

(v) **Fundamental interval** is the range of the thermometer readings at the two fixed points e.g. for thermometers which give direct readings of temperature = $100^0$ C.

## Establishing scales of temperature

(i) Chose a physical property of substance (X)

(ii) Determine the value of the property at the upper fixed point of the thermometer ($X_{100}$). This is done by placing the bulb of the thermometer in steam at 760mmHG until a constant reading is obtained.

(iii) Determine the value of the property at the upper fixed point of the thermometer ($X_0$). This is done by placing the bulb of the thermometer in melting ice at 760mmHG until a constant reading is obtained.

(iv) If the value of the thermometric property at temperature, θ, is $X_\theta$.

Then $\theta = \left(\frac{X_\theta - X_0}{X_{100} - X_0}\right) x\ 100^0$C

## Thermal dynamic scale of temperature

On this scale of temperature is measured in "Kelvin" or K and makes use of triple point only.

If $X_{tr}$ is the value of a thermometric property at the triple point and $X_T$ is the value of thermometric property at temperature, T = $\left(\frac{X_T}{X_{tr}}\ x\ 273.16\right) K$

Using a platinum resistance thermometer

T = $\left(\frac{R_T}{R_{tr}}\ x\ 273.16\right) K$

Where

- $R_T$ is the resistance of the wire at unknown temperature, T.
- $R_{tr}$ is the resistance of the wire at the triple point of water.

### Example 1

The pressure recorded by a constant volume gas thermometer at temperature T is 4.8 x $10^4 Nm^{-2}$. Find T if the pressure at the triple point of water is 4.2 x $10^4 Nm^{-2}$.

Solution

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

T = $\left(\frac{4.8\ x\ 10^4}{4.2\ x\ 10^4}\ x\ 273.16\right) K$ 312.2K

**Absolute zero temperature**

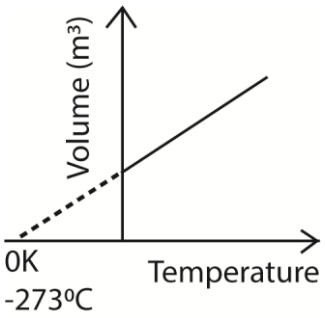
This is the temperature of an ideal gas which corresponds to its zero volume or zero pressure it exerts on the walls of the container in which it is trapped. This value approximates to the triple point of pure water i.e. - $273^0$C or 0K.

## Molecular explanation for existence of absolute zero temperature

When a gas is cooled, its molecules loose kinetic energy continuously since it depends directly on temperature. As molecules lose kinetic energy they move closer into close proximity until when they cease to have kinetic energy. At this point the gas is said to occupy a negligible volume and its temperature at this point is called the absolute zero temperature and the pressure the gas exerts on the walls of the container occupied is negligible.

**Estimating absolute zero temperature**

- Volumes a fixed mass of a gas at various temperatures are determined.
- The volumes of the gas are plotted against corresponding temperature.




Absolute zero temperature is determined by extrapolating the graph until when it touches the temperature axis and is found to be -273$^0$C or 0K.

## Types of thermometers

1. **Liquid in glass thermometer**
   Depends on expansion of the liquid

   **Advantages of liquid-in-glass thermometer.**
   - The thermometer is simple, cheap and portable.
   - The thermometer can be calibrated to give direct readings e.g. clinical thermometer

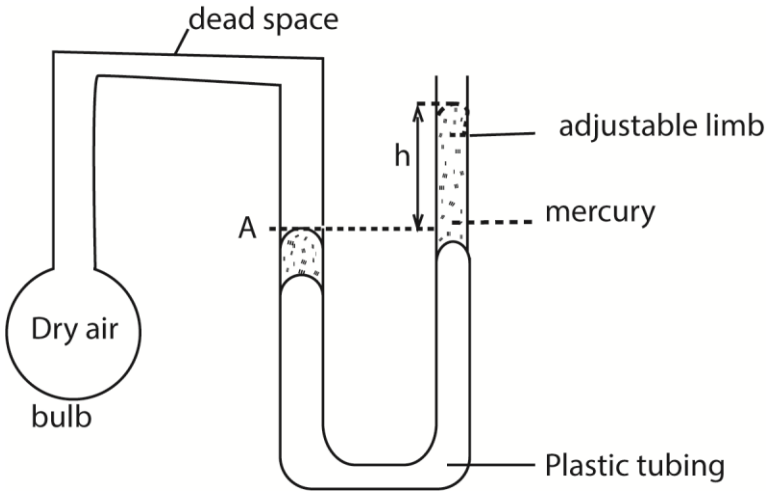
   **Liquids used in thermometers**
   **Mercury**
   Advantages
   - withstands high temperature without change of state
   - does not wet glass
   - expands uniformly

   Disadvantage
   - it is expensive
   - it is poisonous

   **Alcohol**
   Advantage
   - Measures low temperatures because of its low freezing point
   - Cheap

   Disadvantages
   - does not measure high temperature above 78$^0$C.
   - wets glass
   - Water is not used because it has irregular expansion
   - Cannot measure temperatures below 0$^0$Cor above 100$^0$C

**2. Constant volume gas thermometer**




- Place the bulb inside an enclosure whose temperature is to be measured.
- Allow some time for the gas to acquire the temperature of the enclosure. The gas in the bulb may expand and forces mercury up the adjustable tube.
- Adjust the adjustable limb to bring back mercury to constant volume at A and record the height of mercury, $h_\theta$.
- The Celsius scale is given by $\theta = \left(\frac{h_\theta - h_0}{h_{100} - h_0}\right) x\ 100^0 C$ where $h_{100}$ and $h_0$ are the heights at steam and ice points

**Limitations**

- The temperature of the gas in the dead space is different from that of the gas in the bulb
- Thermal expansion of the bulb may lead to change in volume
- Capillary effect on the mercury surface.

Correction

- The dead space should be made small
- The bulb should be made of material with low thermal expansivity
- The manometer tubes should be widened and with the same diameters.

Advantages of constant volume gas thermometers.

- It is very sensitive since a small change in temperature; i.e. small changes in temperature leads to a great expansion of a gas
- Gas thermometers give accurate results since pressure vary linearly with temperature
- Can measure wide range of temperature.

Disadvantages of constant volume gas thermometers

- it is bulky and delicate
- does not give direct readings
- it cannot measure temperature at a point

- it does not measure rapidly changing temperature

**Example 2**

| Value of property | | | |
|---|---|---|---|
| Pressure in mmHg | Ice point | Steam point | Room temperature |
| | 760 | 1040 | 795 |

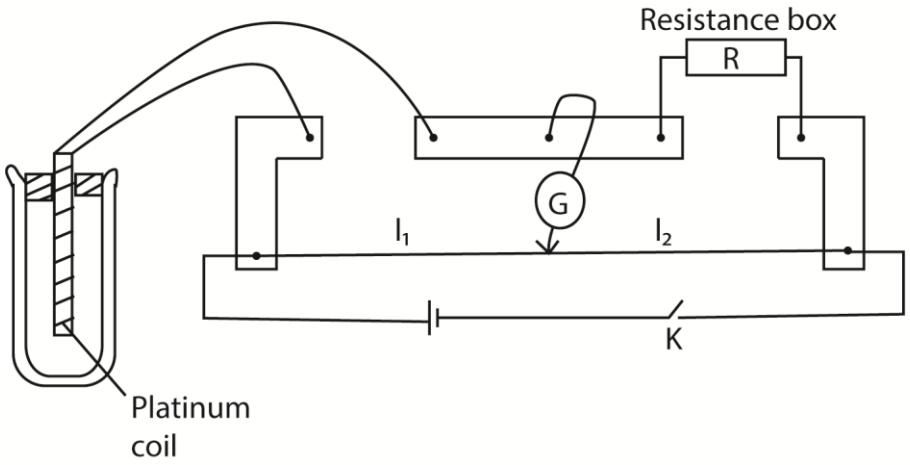
(a) Using the above data, calculate the room temperature on the scale of the constant volume gas thermometer.

$\theta = \left(\frac{P_\theta - P_0}{P_{100} - Ph_0}\right) x\ 100^0C = \left(\frac{795 - 760}{1040 - 760}\right) x\ 100^0C = 12.5^0C$

(b) Explain why a gas thermometer is seldom used for temperature measurements in a laboratory.

Requires the disadvantages of the thermometer

### 3. Resistance thermometer




- Place the resistance thermometer in a funnel with crushed ice and leave it for some time.
- Close the switch and obtain a balance point by adjusting the resistance box,
- Determine the resistance $R_0$ at $0^0C$ from $R_0 = \left(\frac{l_1}{l_2}\right) R$
- Transfer the resistance thermometer into a beaker containing boiling water and after some time, determine resistance $R_{100}$.
- Place the resistance thermometer in water at room temperature and determine resistance $R_\theta$.
- Temperature of the room temperature, $\theta = \left(\frac{R_\theta - R_0}{R_{100} - R_0}\right) x\ 100^0C$

**Advantages**

- It is accurate

- Has fairly wide range of temperature

**Disadvantages**

- Cannot measure temperature at a point
- It cannot be used to follow rapidly changing temperatures

**Example 3**

The resistance of a certain platinum resistance thermometer is found to be 2.56Ω at $0^0$C, 3.56Ω at $100^0$C and 6.78Ω at $444.5^0$C, the boiling point of sulphur on the gas scale

(a) Calculate boiling point of sulphur on the platinum resistance scale.

$\theta = \left(\frac{R_\theta - R_0}{R_{100} - R_0}\right) x\ 100^0C$

$= \left(\frac{6.78 - 2.56}{3.56 - 2.56}\right) x\ 100$

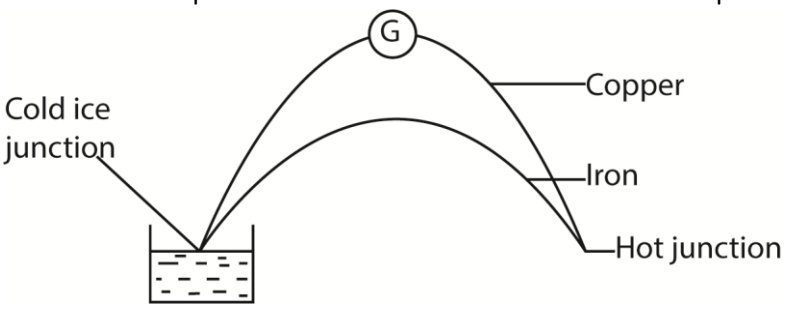
$= 422^0$C

(b) Why are the two values of boiling point of sulphur differ

Different thermometric properties in different thermometers vary differently with temperatures

**4. Thermocouples**

It consists of different metals such as copper and iron joined in a circuit and their junctions kept at different temperatures. This causes a small current to be produced




**Mode of action**

- The cold junction is put in water at $0^0$C and e.m.f, $E_0$ is determined.
- The other junction is put at a point whose temperature is required
- As a result of difference in temperature, a thermal e.m.f is induced and causes a deflection of the galvanometer, $E_\theta$.
- The hot junction is placed at steam point and e.m.f, $E_{100}$ is determined

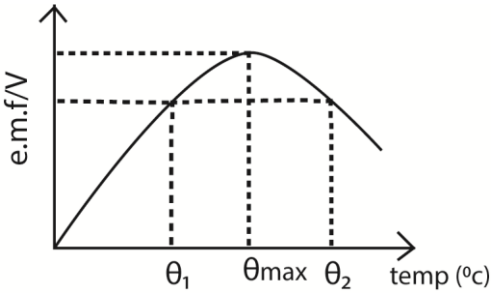
Then $\theta^0$C = $\left(\frac{E_\theta - E_0}{E_{100} - E_0}\right) x\ 100^0C$

**Advantages of a thermocouple**

- Can be used to measure temperature at a point
- Can measure rapidly changing temperature
- Can give direct readings
- Has wide range

**Disadvantages of a thermocouple**

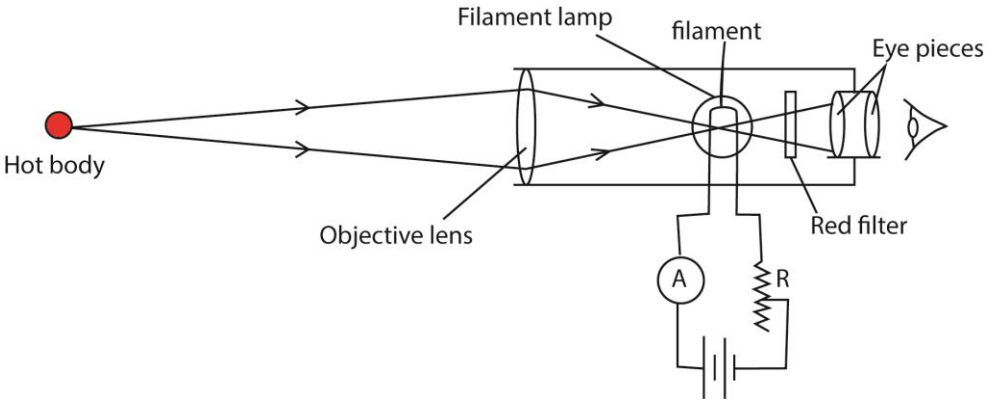
- Not accurate
- Two values of temperature θ1 and θ2 may correspond to one e.m.f




**5. Pyrometers**

A pyrometer is a thermometer used to measure very high temperatures by using the radiation that the body emits and wavelength of the radiation as the thermometric property.

Optical pyrometer




- the filament is focused on the eye piece and the objective focuses the object so that the image of the object lies in the same plane as the filament
- Light from the hot object and the filament is passed through the red filter and viewed by the eyepiece.
- Current is adjusted by the rheostat R until the filament and the object are equally bright.
- The temperature of the hot body is then read from the calibrated ammeter, A.

**Revision Exercise (qns. for different global examination bodies)**

1. (a) Define the following:
   (i) Triple point of water (01 marks)
   It the temperature and pressure at which a vapour, liquid and solid of a substance coexist at equilibrium.
   (ii) Absolute zero temperature (01mark)
   It is the minimum temperature on thermodynamic scale i.e. 0K.

(b) Explain why triple point of water is taken as a standard in modern thermometry instead of ice and steam points. (04 marks)

It is constant, reproducible and not affected by pressure variations and impurities in water.

(c) (i) What is a **thermometric property**? (01 marks)

Thermometric property is a physical measurable property that varies linearly and continuously with temperature and is constant at constant temperature.

(ii) State **three** qualities of a good thermometric property? (03mark)

- should vary linearly with change in in temperature
- Should vary continuously with temperature
- Should be sensitive to temperature changes
- Should be measurable
- Should vary over a wide range of temperature.

(d)(i) A constant volume thermometer was used to measure temperature when the atmospheric pressure was 760mmHg.

The following values were obtained.

| | Length of Mercury in closed limb (mmHg) | Length of Mercury in open limb (mmHg) |
|---|---|---|
| Bulb in ice | 140 | 130 |
| Bulb in steam | 140 | 330 |
| Bulb at room temperature | 140 | 170 |

Calculate the room temperature. (05marks)

Room temperature = $\frac{170-130}{330-130}x100 = 20^0C$

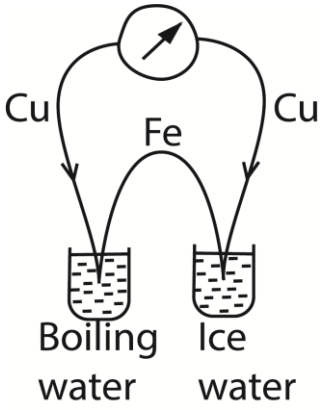
(ii) List two advantages of the constant volume gas thermometer over the mercury in glass thermometer. (02 marks)

- it has a wide range
- very accurate
- very sensitive

(e) Explain what happens when the temperature of a fixed mass of ice is raised from $0^0$C to $10^0$C. (03marks)

- Temperature remains constant until all the ice has melted and then temperature of water increases to from $0^0$C to $10^0$C.
- The volume decreases up to $4^0$C and then increase as temperature increases to $10^0$C.

2. (a) (i) Explain how a thermocouple is used to measure temperature on a Celsius scale. (05marks)




The e.m.f, $E_{Tr}$ is obtained when a hot junction is placed in water at triple point.

E.m.f, $E_T$ is obtained at unknown temperature T.

T= $\frac{E_T}{E_{Tr}}\ x\ 273.16K$

(ii) State two advantages of a thermocouple. (01mark)

- Used to measure rapidly changing temperature
- It can give direct readings
- It is not bulky
- It can measure temperature at a point

(b)(i) Define thermometric property (01mark)

Thermometric property is a physical measurable property that varies linearly and continuously with temperature and is constant at constant temperature.

(ii) Define how a liquid-in-glass thermometer can be used to measure temperature in degrees Celsius. (04marks)

- A bulb is inserted in pure ice-water mixture.
- After some time, the length $l_0$ of mercury thread is recorded.
- The bulb is inserted in steam and constant length $l_{100}$ of mercury thread is recorded.
- When $l_\theta$ is the length of mercury thread inserted in an unknown enclosure of temperature, $\theta^0$, then;

  $\theta = \left(\frac{l_\theta - l_0}{l_{100} - l_0}\right) x\ 100^0C$

(iii) A thermometer is constructed with a liquid which expands according to relation.

$V_t = V_0(1 + \alpha t + \beta t^2)$. Where $V_t$ is the volume at $t^0C$ and $V_0$ is the volume at $0^0C$ on the scale of the gas thermometer and α and β are constants.

Given that α = 1000β, what will the liquid thermometer read when the gas thermometer reads $50^0C$.

Using $\theta = \left(\frac{V_\theta - V_0}{V_{100} - V_0}\right) x\ 100^0C$

$V_{50} = V_0(1 + \alpha(50) + \beta(50)^2)$.

$V_{100} = V_0(1 + \alpha(100) + \beta(100)^2)$.

$\theta = \left(\frac{V_0(1+50000\beta+2500\beta) - V_0}{V_0(1+100000\beta+10000\beta) - V_0}\right) x\ 100^0 C$

$= 47.73^0$C

3. (a) Define the following quantities:
   (i) Thermometric property (01mark)
   Thermometric property is a physical measurable property that varies linearly and continuously with temperature and is constant at constant temperature.

   (ii) Specific heat capacity (01mark)
   Specific heat capacity is the amount of heat requires to raise the temperature of 1kg mass of a substance by 1K or $1^0$C

   (b) (i) state two examples of commonly used thermometric properties. (01mark)

   - Volume of constant mass of a gas at constant pressure
   - Pressure of a gas at constant volume
   - Electrical resistance of a platinum wire
   - e.m.f of a thermocouple

   (ii) Describe briefly how to determine the lower and upper fixed points for an uncalibrated liquid-in-glass thermometer (04marks)

   - the bulb of the thermometer is immersed in pure ice-water mixture; the level of liquid column falls to a constant length. The level of the liquid column is marked and is the lower fixed point.
   - the bulb of the thermometer is then immersed in steam from pure water; the level of liquid column rises to a constant length. The level of the liquid column is marked and is the upper fixed point.

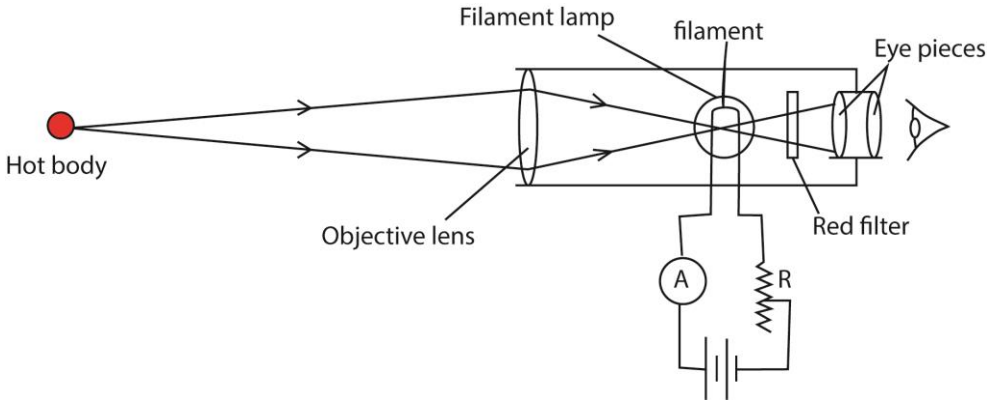
4. (a) (i) State the thermometric property used in a constant-volume gas thermometer (01mark)
   pressure
   (ii) Give two characteristic of a good thermometric property, (02marks)
   - should vary linearly with change in in temperature
   - Should vary continuously with temperature
   - Should be sensitive to temperature changes
   - Should be measurable
   - Should vary over a wide range of temperature.

   (b) (i) Describe the steps taken to set up a Celsius scale of temperature for a mercury-in glass thermometer. (04marks)
   - A bulb is inserted in pure ice-water mixture.
   - After some time, the length l0 of mercury thread is recorded.
   - The bulb is inserted in steam and constant length l100 of mercury thread is recorded.
   - When lθ is the length of mercury thread inserted in an unknown enclosure of temperature, $\theta^0$, then $\theta = \left(\frac{l_\theta - l_0}{l_{100} - l_0}\right) x\ 100^0 C$

(ii) State four disadvantages of mercury in glass thermometer. (04marks)

- it is not very sensitive
- it cannot measure rapidly changing temperature
- it is delicate, i.e. it breaks easily

(c) Describe with the aid of a diagram the operation of an optical pyrometer (06marks)




- the filament is focused on the eye piece and the objective focuses the object so that the image of the object lies in the same plane as the filament
- Light from the hot object and the filament is passed through the red filter and viewed by the eyepiece.
- Current is adjusted by the rheostat R until the filament and the object are equally bright.
- The temperature of the hot body is then read from the calibrated ammeter, A.

5. (a)(i) Define the term thermometric property and give four examples (03marks)

Thermometric property is a physical property whose value varies uniformly and continuously with change in temperature.

Examples

- Volume of constant mass of a gas at constant pressure
- Pressure of a gas at constant volume
- Electrical resistance of a platinum wire
- e.m.f of a thermocouple
-

(ii) State two qualities of a good thermometric property. (01mark)

- Should vary linearly and continuously with temperature
- Should be sensitive to temperature change
- Should vary over a wide range of temperature.

(b) (i) With reference to a liquid in glass thermometer, describe the step involved in setting up a Kelvin scale of temperature (03marks)

Length $l_{tr}$ of a liquid column is measured at the triple point of water

Length $l_T$ of liquid column is measured at unknown temperature, T

T = $\frac{l_T}{l_{tr}}\ x\ 273.16K$

(ii) State one advantage and one disadvantage of the resistance thermometer. (01mark)

Advantage

- measures a wide range of temperatures
- very accurate

Disadvantage

- unsuitable for rapidly changing temperatures
- Cannot measure temperature at a point
- Does not give direct readings

(d) A resistance thermometer has resistance of 21.42Ω at the ice point, 29.10Ω at steam point and 28.11Ω at some unknown temperature θ. Calculate θ on the scale of this thermometer. (03marks)

$\theta = \frac{R_\theta - R_0}{R_{100} - R_0} x\ 100^0C = \frac{28.11-21.42}{29.10-21.42}\ x\ 100^0C$ = 87.11$^0$C

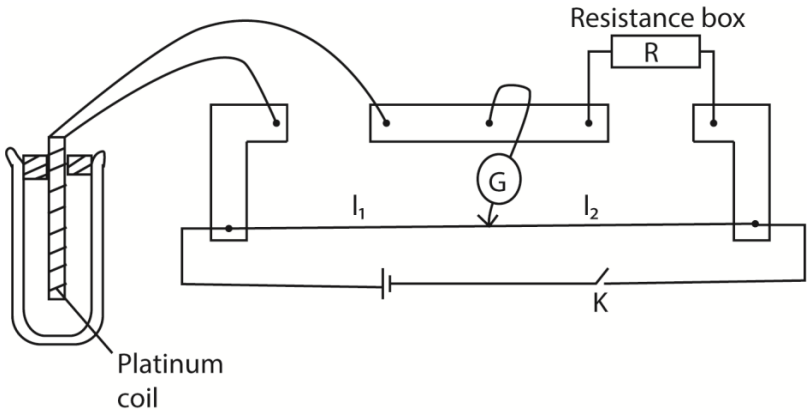
6. (a) (i) Define the term thermometric property. (01mark)

Thermometric property is a physical property that vary uniformly and continuously with temperature.

(i) State two thermometric properties. (01mark)

- Volume of constant mass of a gas at constant pressure
- Pressure of a gas at constant volume
- Electrical resistance of a platinum wire
- e.m.f of a thermocouple

(ii) With the aid of a labeled diagram, describe how the room temperature can be measured using uncalibrated resistance thermometer. (06marks)




- Place the resistance thermometer in a funnel with crushed ice and leave it for some time.
- Close the switch and obtain a balance point by adjusting the resistance box,
- Determine the resistance $R_0$ at 0$^0$C from $R_0 = \left(\frac{l_1}{l_2}\right) R$
- Transfer the resistance thermometer a beaker containing boiling water and after some time, determine resistance $R_{100}$.
- Place the resistance thermometer in water at room temperature and determine resistance $R_\theta$.
- Temperature of the room temperature, θ = $\left(\frac{R_\theta - R_0}{R_{100} - R_0}\right) x\ 100^0C$

7. (a) (i) Define a thermometric property and give two examples (02marks)

Thermometric property is a physical measurable property that varies linearly and continuously with temperature and is constant at constant temperature.

Examples

- Volume of constant mass of a gas at constant pressure
- Pressure of a gas at constant volume
- Electrical resistance of a platinum wire
- e.m.f of a thermocouple

(ii) When is the temperature of 0K attained? (02marks)

Ok is when molecules of a substance slow down and attain their minimum total energy

(b)(i) With reference to constant-volume gas thermometer, define temperature on the Celsius scale (02marks)

$\theta = \frac{P_\theta - P_0}{P_{100} - P_0}$ where θ is unknown temperature, $P_\theta$ is the pressure at unknown temperature, $P_0$ is the pressure at ice point and $P_{100}$ is the pressure at steam point.

(ii) State two advantages and two disadvantages of the constant-volume gas thermometer. (02marks)

Advantages

- it has a wide range
- very accurate

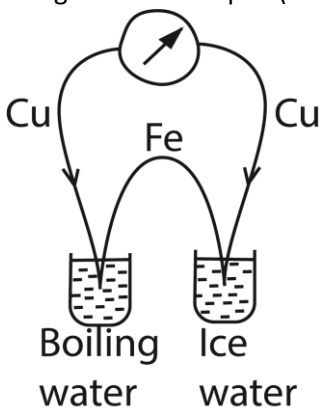
Disadvantages

- it does not give direct reading
- cannot measure rapidly changing temperatures.

(c) (i) Define triple point of water (01mark)

Triple point of water is the temperature and pressure at which saturated water vapour, pure water and ice coexist in equilibrium.

(ii) Describe how you would measure the temperature of a body on the thermodynamic scale using a thermocouple. (03marks)




The e.m.f, $E_{Tr}$ is obtained when a hot junction is placed in water at triple point. E.m.f, $E_T$ is obtained at unknown temperature T.

$T = \frac{E_T}{E_{Tr}}\ x\ 273.16K$

(d) The resistance, $R_\theta$ of platinum varies with the temperature $0^0C$ as measured by the constant-volume gas thermometer according to the equation

$R_\theta = 50.0 + 0.17\theta + 3.0 \times 10^{-4}\theta^2$

(i) Calculate the temperature on the platinum scale corresponding to $60^0C$ on the gas scale. (06marks)

$R_0 = 50\Omega$

$R_{60} = 50 + 0.17 \times 60 + 3.0 \times 10^{-4} \times 60^2 = 61.28\Omega$

$R_{100} = 50 + 0.17 \times 100 + 3.0 \times 10^{-4} \times 100^2 = 70.00\Omega$

$\theta = \frac{R_\theta - R_0}{R_{100} - R_0}\ x\ 100^0C$

$= \frac{61.28 - 50}{70 - 50}\ x\ 100$

$= 56.4^0C$

(ii) Account for the difference between the two values and state the temperatures at which they agree. (02marks)

Difference thermometric properties vary differently with temperature.

8. (a) What is meant by:

(i) Thermometric property (01mark)

Thermometric property is a physical property that vary uniformly and continuously with temperature.

(ii) Triple point (01mark)

It the temperature and pressure at which a vapour, liquid and solid of a substance coexist at equilibrium.

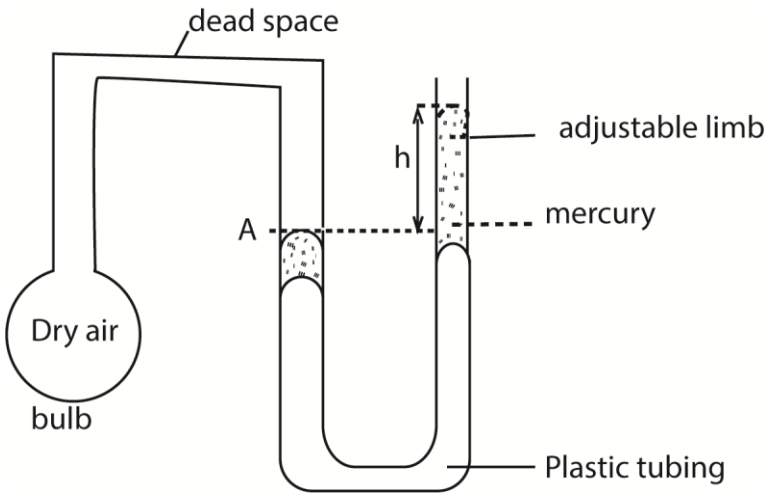
(b) (i) Describe the steps taken to establish a temperature scale. (05marks)

- Choose a thermometric property
- Find its value, $x_{100}$ at steam point and value $x_0$ at ice point.
- If the value of thermometric property is $x_\theta$ at temperature $\theta$
- Then $\theta = \frac{x_\theta - x_0}{x_{100} - x_0}$

(ii) Explain why two thermometers may give different values for the same unknown temperature. (02marks)

Two thermometers based on different thermometric property may show different temperatures because thermometric properties vary differently with change in temperature.

(c) (i) Describe, with the aid of a diagram, how a constant-volume gas thermometer may be used to measure temperature. (06mrks)




- Place the bulb inside whose temperature is to be measured.
- Allow some time for the gas to acquire the temperature of the enclosure. The gas in the bulb may expand and forces mercury up the adjustable tube.
- Adjust the adjustable limb to bring back mercury to constant volume at A and record the height of mercury, $h_\theta$.
- The Celsius scale is given by $\theta = \left(\frac{h_\theta - h_0}{h_{100} - h_0}\right) x\ 100^0 C$ where $h_{100}$ and $h_0$ are the heights at steam and ice points

(ii) State three corrections that need to be made when using the thermometer in (c)(i) above. (03marks)

- The bulb should be made of glass with low thermal expansivity
- Dead space should be narrowed
- The bulb should be thin to allow easy penetration of heat

(iii) State and explain the sources of inaccuracies in using mercury in glass thermometer, (02marks)

- Non uniformity the mercury tube
- Temperature of air in dead space being different from that in the bulb

**Thank you**
**Dr. Bbosa Science**