Chapter 8 – Temperature

Subject content

Content
- Principles of thermometry

Learning outcomes
(a) explain how a physical property which varies with temperature, such as volume of liquid column, resistance of metal wire and electromotive force (e.m.f.) produced by junctions formed with wires of two different metals, may be used to define temperature scales
(b) describe the process of calibration of a liquid-in-glass thermometer, including the need for fixed points such as the ice point and steam point

Definitions

Term	Definition	SI unit
Temperature	degree / measurement of hotness / coldness of object	kelvin (K)
Heat	amount of thermal energy that is transferred from hotter → colder region	joule (J)
Thermometric substance	substance with physical properties that vary continuously + linearly with temperature for range of temperatures measured	
Ice point (lower fixed point)	temperature of pure melting ice at 1 atm	0°C
Steam point (upper fixed point)	temperature of steam from boiling water at 1 atm	100°C

Formulae

Calculate temperature using calibrated thermometer

$$\theta^{\circ}\mathrm{C} = \frac{x_\theta - x_0}{x_{100} - x_0} \times 100^{\circ}\mathrm{C}$$

where x_θ = value of thermometric property at unknown temperature θ°C
x_0 = value of thermometric property at 0°C
x_{100} = value of thermometric property at 100°C

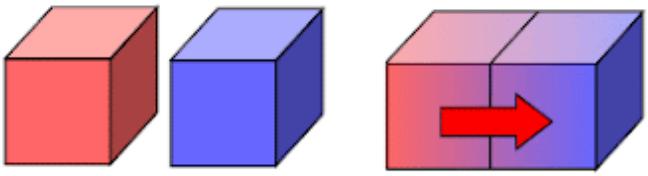
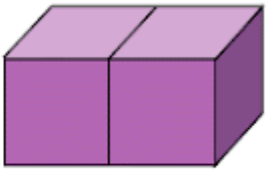
liquid-in-glass	resistance	thermocouple	
$\theta^{\circ}\mathrm{C} = \frac{l_\theta - l_0}{l_{100} - l_0} \times 100^{\circ}\mathrm{C}$	$\theta^{\circ}\mathrm{C} = \frac{R_\theta - R_0}{R_{100} - R_0} \times 100^{\circ}\mathrm{C}$	$\varepsilon \propto \Delta\theta$	$\frac{\varepsilon_1}{\Delta\theta_1} = \frac{\varepsilon_2}{\Delta\theta_2}$

Generalised equation:

$$\theta°\text{C from } n°\text{C} = \frac{x_\theta - x_n}{x_m - x_n} \times (\text{m} - \text{n})\,°\text{C}$$

8.1 Measurement of Temperature

Heat transfer:

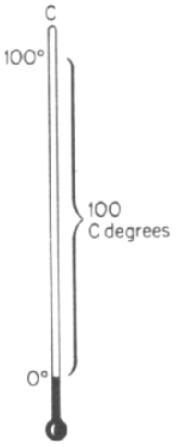
Hot + cold body in contact (conduction)	Bodies at same temperature
net heat transfer (hot → cold)	no net heat transfer (thermal equilibrium)
	

Thermometer

- Measure temperature
- Use **thermometric substances**
  → physical properties vary continuously + linearly with temperature for range of temperatures measured (**thermometric properties**)
- Types:

Thermometric property	Thermometer
1. **Volume** of fixed mass of liquid	Liquid-in-glass thermometer 1) mercury 2) alcohol
2. Electrical voltage / electromotive force (**e.m.f.**) across 2 metallic junctions	Thermocouple thermometer
3. Electrical **resistance** of metal (wire)	Resistance thermometer (e.g. oral)

- Features of good thermometer
  1. easy-to-read scale
  2. safe to use
  3. responsive to temperature changes
  4. sensitive to small temperature changes
  5. able to measure required range of temperature



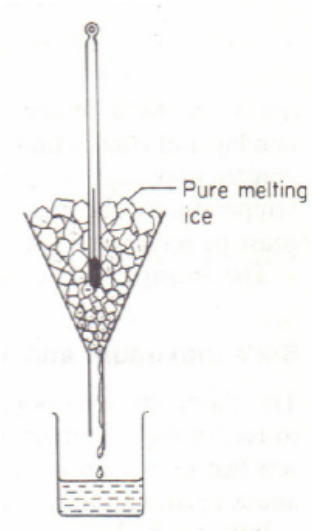
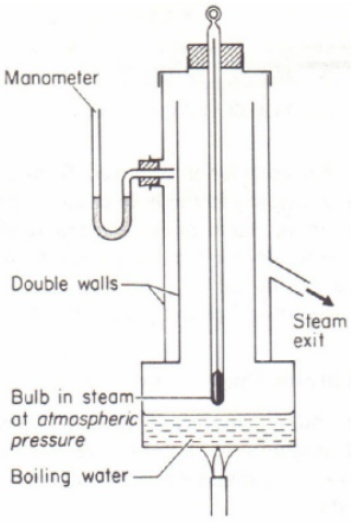
Construct thermometer showing **Celsius scale**:

1. Choose appropriate thermometric substance (alcohol / mercury)
2. Choose 2 fixed points (easily obtainable + reproducible)
   1) ice point (0°C) → lower fixed point
   2) steam point (100°C) → upper fixed point
3. Record values of thermometric property at 2 fixed points
4. Divide interval → 100 equal parts (each represent 1°C)

8.2 Calibrating a Thermometer

Liquid-in-glass thermometer

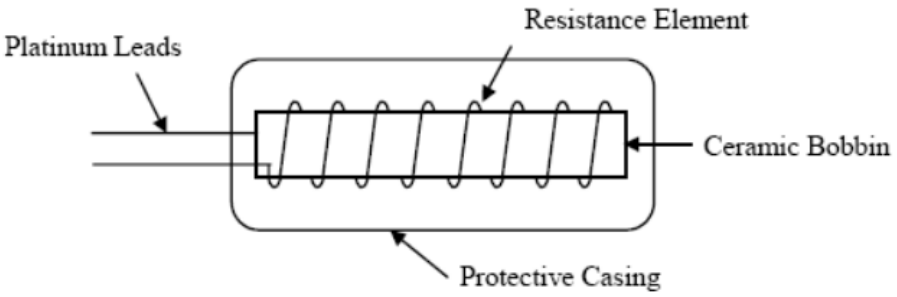
Ice point & steam point:

Ice point	Steam point
	
1. Thermometer is placed in pure crushed melting ice 2. A mark is made on thermometer to indicate level of liquid column at the temperature	1. Thermometer is placed in steam, above boiling water (hypsometer) 2. A mark is made on thermometer to indicate level of liquid column at the temperature
1. Use crushed ice instead of ice cubes ● fill air pockets ● fully cover thermometer bulb in ice (consistent temperature) 2. Inaccurate temperature reading ● crushed ice has not started melting (temperature < 0°C) ● too much ice melted, water unable to flow out, gain heat (temperature > 0°C) 3. Funnel allows melted ice to flow away ● measure only temperature of melting ice ● melted ice absorbs heat from surrounding, temperature > 0°C	1. Mercury bulb of thermometer suspended above boiling water instead of being immersed totally ● boiling point of impure water > 100°C ● steam: definitely pure ● thermometer bulb at 100°C when steam condenses on it 2. Use manometer to check pressure inside apparatus = atmospheric pressure outside ● adjust flame to change pressure inside

Formula:

$$\theta^{\circ}\mathrm{C} = \frac{l_{\theta} - l_{0}}{l_{100} - l_{0}} \times 100^{\circ}\mathrm{C}$$

Resistance thermometer

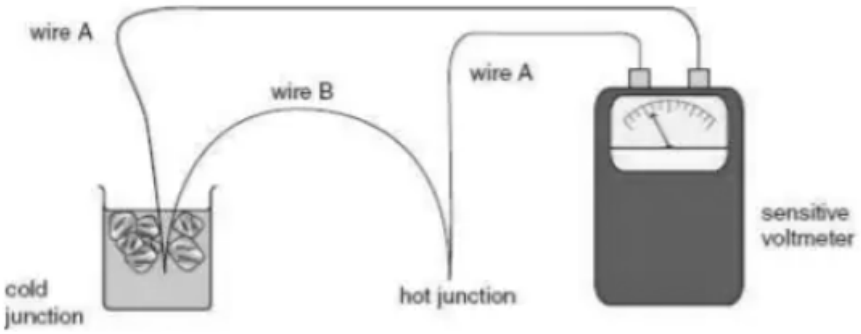


Resistance thermometer

- Use thermometric property of electrical resistance of metallic conductors (e.g. platinum)
- Long platinum wire wound around piece of mica in a silica tube
- Formula:

$$\theta^{\circ}\mathrm{C} = \frac{R_{\theta} - R_{0}}{R_{100} - R_{0}} \times 100^{\circ}\mathrm{C}$$

Thermocouple thermometer



Thermocouple thermometer

- 2 types of wires made of different metals:
  1. iron
  2. copper
- Ends of wires are joined → 2 junctions
- Temperature difference between 2 junctions → potential difference generated → electrical voltage / electromotive force (e.m.f.) → indicated by voltmeter
- Greater difference between temperatures of junctions, greater voltage / e.m.f. produced across junctions
- Calibrate → determine voltage difference at junctions:

1. **2 fixed points** (ice + steam point)
2. **ice / steam point + temperature** θ

- Equations:

$\varepsilon \propto \Delta\theta$	$\frac{\varepsilon_1}{\Delta\theta_1} = \frac{\varepsilon_2}{\Delta\theta_2}$
where ε = e.m.f. across 2 junctions (in V) $\Delta\theta$ = temperature difference between 2 junctions (in °C)	

Typical questions

Multiple choice questions

1 The diagrams show the scale on a voltmeter connected to a thermocouple thermometer.

What is the temperature of the liquid? (2013 P1 Q22)

A 30°C
B 40°C
C 70°C
D 80°C

2 The thermal properties of various materials have some useful applications.
Which device makes use of the thermal expansion of a liquid? (2014 P1 Q18)

A hydraulic press
B liquid-in-glass thermometer
C manometer
D thermistor

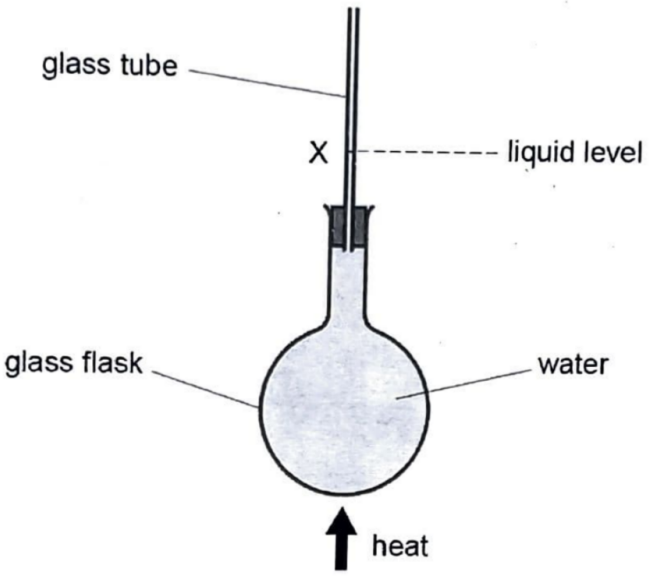
3 Which two physical properties may both be used to define temperature scales? (2016 P1 Q19)

A e.m.f. at the junction of two different metals and volume of a liquid column
B mass of a solid object and resistance of a metal wire
C mass of a solid object and volume of a liquid column
D volume of a liquid column and weight of a trapped gas

4 Physical properties of materials are used in the measurement of temperature.
Which physical property is **not** suitable for this purpose? (2018 P1 Q19)

A expansion of a metal
B mass of a liquid
C resistance of a metal
D volume of a liquid

5 The figure below shows apparatus used to show expansion.

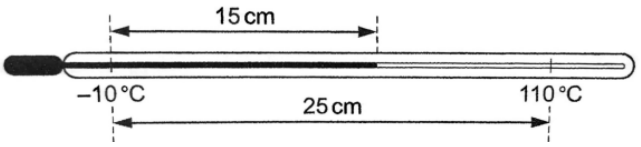


The glass flask, full of water, is heated. A student is surprised when the liquid level X in the glass tube falls for a few seconds before it rises. Why does the liquid level fall and why does it then rise?

	Liquid level falls because:	Liquid level rises because:
A	water contracts first	water contracts more than glass
B	water contracts first	glass contracts more than water
C	glass expands first	water expands more than glass
D	glass expands first	glass expands more than water

Structured questions

1 The length of the mercury thread of a laboratory thermometer between the -10°C mark and the 110°C is 24 cm. What is the temperature recorded below?



θ°C from -10°C = $\frac{15}{25}$× 120°C = 72°C

θ°C = 72°C + (-10°C) = 62°C

2 Describe how to check that the lower fixed point is marked correctly on a liquid-in-glass thermometer. [2]

(2015 P2A Q5)

The lower fixed point of a liquid-in-glass thermometer is usually the temperature of melting ice (0°C). As such, the bulb of the thermometer should be fully submerged in a flask of melting ice. The reading is taken when there is no visible movement of the stem of the thermometer, and the reading should correspond to 0°C.

3 Explain how a thermocouple thermometer can be used for measuring

(a) high temperature [1]

Metals used at junctions have high melting points.

(b) rapidly changing temperature [1]

Junctions have small mass, thus small heat capacity.
(minimal heat is required to change their temperature)

4 Simon uses an aluminium can, a drinking straw and some plasticine to make a simple thermometer. He pours a liquid that expands linearly with temperature into the can.

(a) He chooses two fixed points of Celsius scale to calibrate his thermometer. Describe them. [2]

The ice point (lower fixed point) is temperature of pure melting ice at 1 atmosphere.
The steam point (upper fixed point) is temperature of steam from boiling water at 1 atm.

(b) Why should he use a drinking straw of small and constant diameter? [2]

- Increase sensitivity of the thermometer (measure small temperature changes + obtain readings clearly)

- Ensure height of liquid varies linearly with temperature changes (constant cross-sectional area of fixed mass of liquid)