Unit 5: Temperature

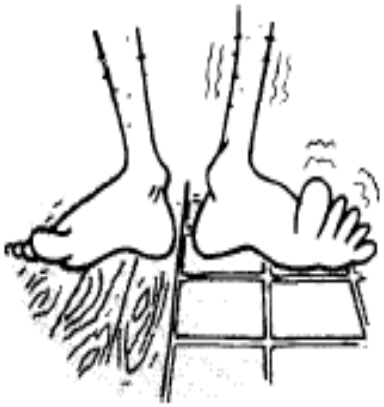
Learning Outcomes

Students should be able to:

1. Explain how the volume of a fixed mass of liquid may be used to define temperature scale and state examples of other such properties.
2. Explain the need for fixed points and state what is meant by ice point and steam point.
3. Explain how a thermocouple thermometer works.

How do we measure temperature?

1. Stand with one foot on a tiled floor and one foot on a wooden floor. The floor is all at the same temperature, but does it feel so?



How do we measure temperature?

2. Try putting your left and right hands into 2 cans of water of different temperature as shown in the diagram below.

   Then place both hands into the centre pot of water. What would you feel?

How do we measure temperature?

- Is our skin a good gauge of temperature?
- How can we obtain accurate measurements of temperature?

Temperature and Heat

- Temperature is a measure of the degree of ‘hotness’ or ‘coldness’ of a body
- Heat is the amount of internal thermal energy in an object

SI unit for Temperature

- SI unit for temp is **Kelvin**, K (not degree celsius!!!)

- To convert degree Celsius to Kelvin:
  T (Kelvin) = θ (Celsius) + 273

Example,
17°C in K: T = (17 + 273) = 290 K

360K in °C: θ = (360 – 273) = 87 °C

Ice Point	0 °C	273 K
Steam Point	100 °C	373 K
Absolute Zero	-273 °C	0 K

http://www.allmeasures.com/temperature.html

*Fahrenheit Scale: °F = °C × 1.8 + 32

Example

Convert a) 45°C into Kelvin,

b) 823 K into degrees Celsius

- a) 45°C = 45 + 273 = 318 K
- b) 823 K = 823 – 273 = 550 °C

How do we measure temperature?

- The thermometer is an instrument used to measure temperature accurately.
- It makes use of the physical properties of substances such as mercury that vary continuously and linearly with temperature.
- They are called thermometric substances.

How do we measure temperature?

Thermometric substances

	Physical Property	Thermometer
	Volume of a fixed mass of liquid	Mercury-in-glass thermometer, Alcohol-in-glass thermometer
	Electromotive force	Thermocouple
	Resistance of a piece of metal	Resistance thermometer
	Pressure of fixed mass of gas at constant volume	Constant-volume gas thermometer

Types of Thermometers

Galileo Thermometer

Resistance Thermometer

Maximum Minimum Thermometer

Infrared Thermometer

Bimetallic Thermometer

Thermocouple Thermometer

What makes a good thermometer?

- An easy-to-read scale
- Linearity
- Safe to use
- Responsive to temperature changes
- Sensitive to small temperature changes
- Able to measure a wide range of temperatures

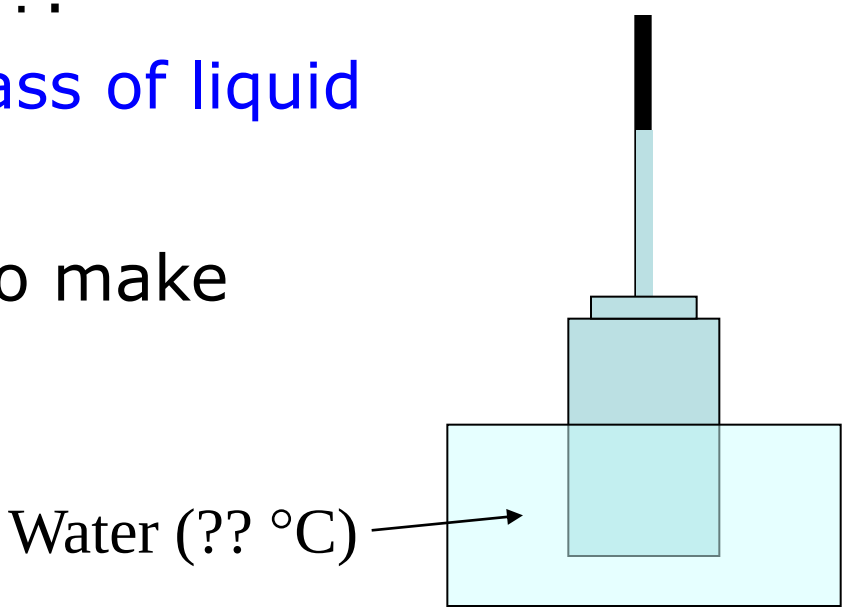
How do we measure temperature?

A home-made thermometer using a jar and a straw

Physical property used ?:

volume of a fixed mass of liquid

Can you suggest how to make it read temperature?



Constructing a temperature scale (Calibrating a thermometer)

Step 1: **Choose an appropriate substance**

Choose a suitable thermometric substance and its physical properties

e.g. Volume of mercury which varies

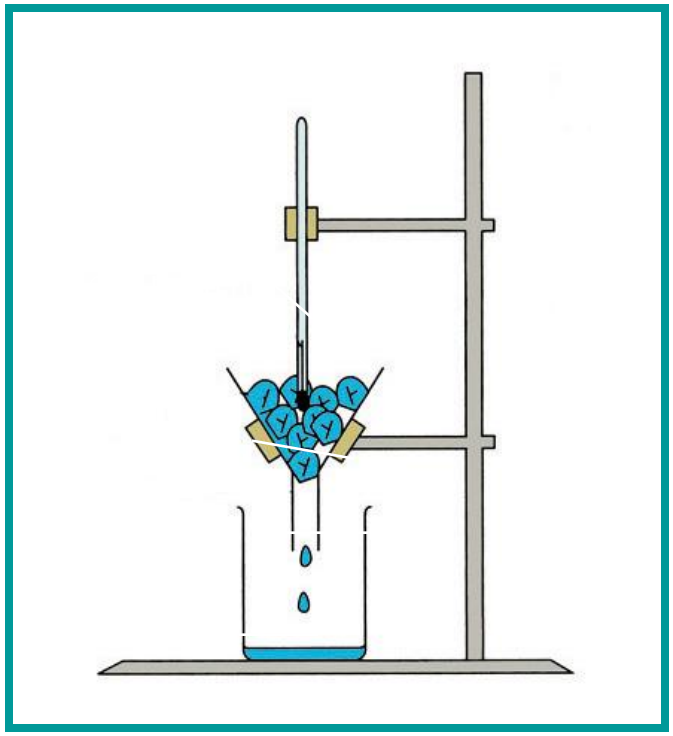
continuously with changes in temperature

Constructing a temperature scale

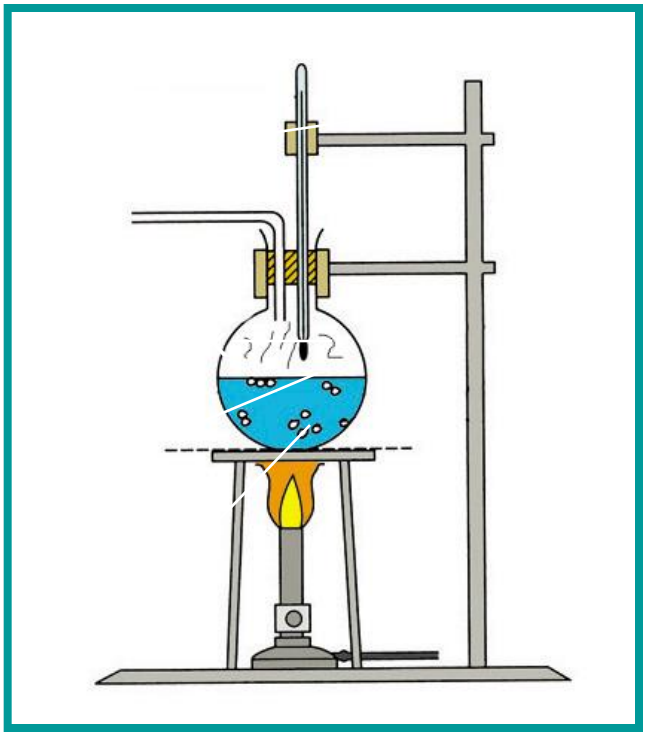
Step 2: **Choose two fixed points**

- Choose two standard degrees of hotness or coldness which are easily obtainable and reproducible. These are called **fixed points**.
- The two fixed points for the Celsius Scale are:
  - Temperature of pure melting ice at one atmospheric pressure – **ice point (Lower fixed point**)
  - Temperature at which boiling water changes into steam at one atmospheric pressure – **steam point (Upper fixed point)**
- Record the values of the physical property (e.g. length of mercury column) of substance at these two fixed points.

Constructing a temperature scale



finding the ice point



finding the steam point

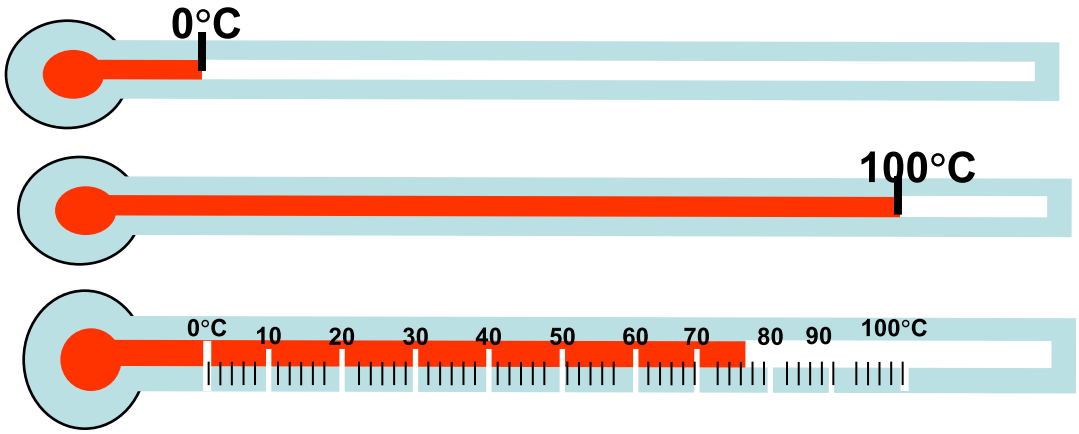
Why are ice point and steam points chosen?

- Easily obtainable and reproducible
- For purpose of standardisation

Constructing a temperature scale

Step 3: **Set up the scale**

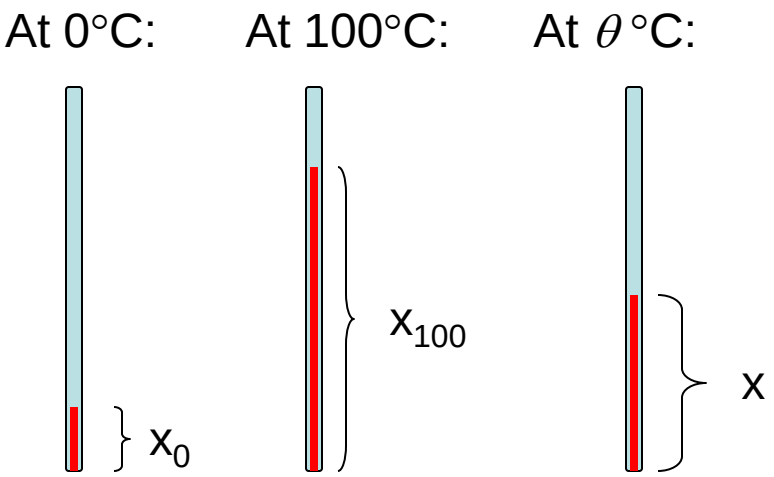
When two fixed points are marked, the temperature between them are divided into equal divisions so that temperatures can be read easily and precisely



Using the Celsius Scale, the interval between the fixed points is divided into 100 equal divisions.

Each division is 1 degree Celsius (°C)

Calculating the Temperature on an Unmarked Thermometer



$$\theta = \frac{x - x_0}{x_{100} - x_0} \times 100°C$$

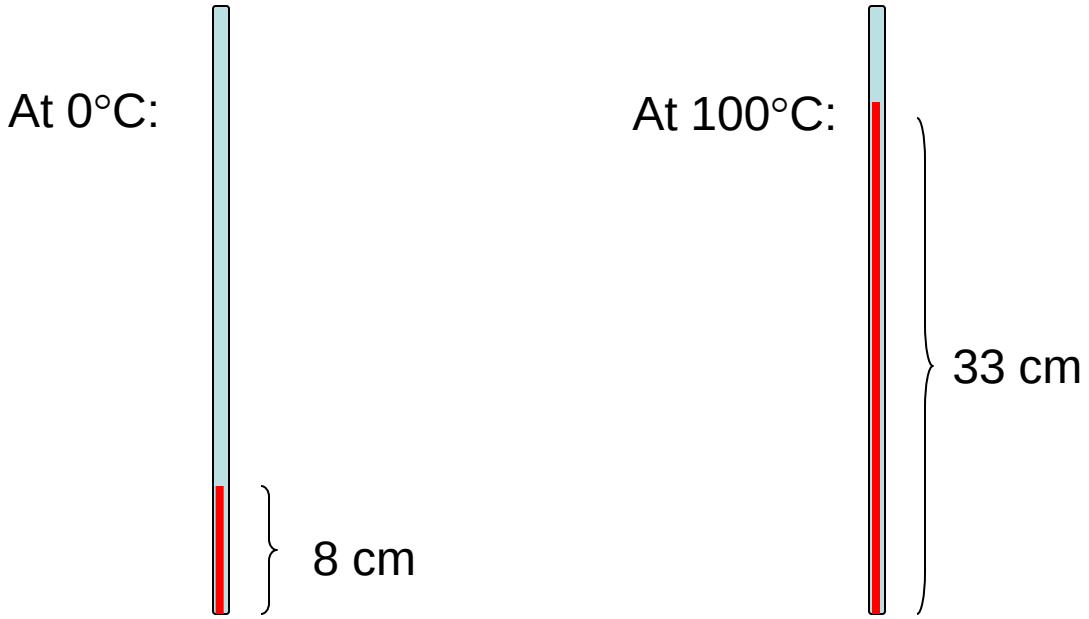
where x_o = length of liquid thread at ice point

x_{100} = length of liquid thread at steam point

x = length of liquid thread at θ °C

Example

At 0°C, the length of the mercury thread, l_0 was 8cm and at 100°C, the length of the mercury thread, l_{100} was 33cm. What is the temperature when the mercury thread, l_θ is a) 26cm, b) 3cm?



Example (a)

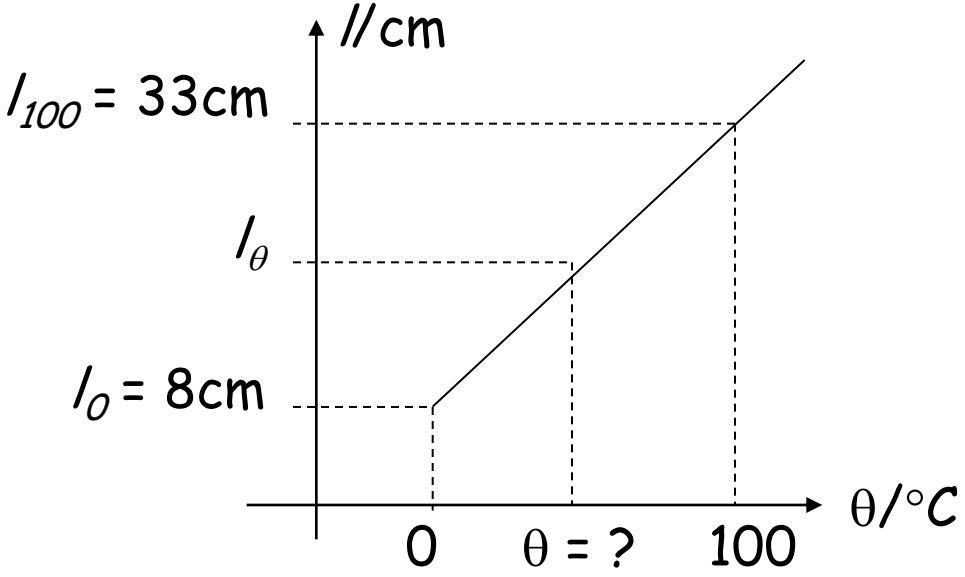
When l_θ is 26cm,

By calculation,

$$\theta = \frac{l_\theta - l_0}{l_{100} - l_0} \times 100$$

$$\theta = \frac{26 - 8}{33 - 8} \times 100 = 72\,^{\circ}\mathrm{C}$$

Graphically,



$$\frac{l_\theta - l_0}{\theta - 0} = \frac{l_{100} - l_0}{100 - 0}$$

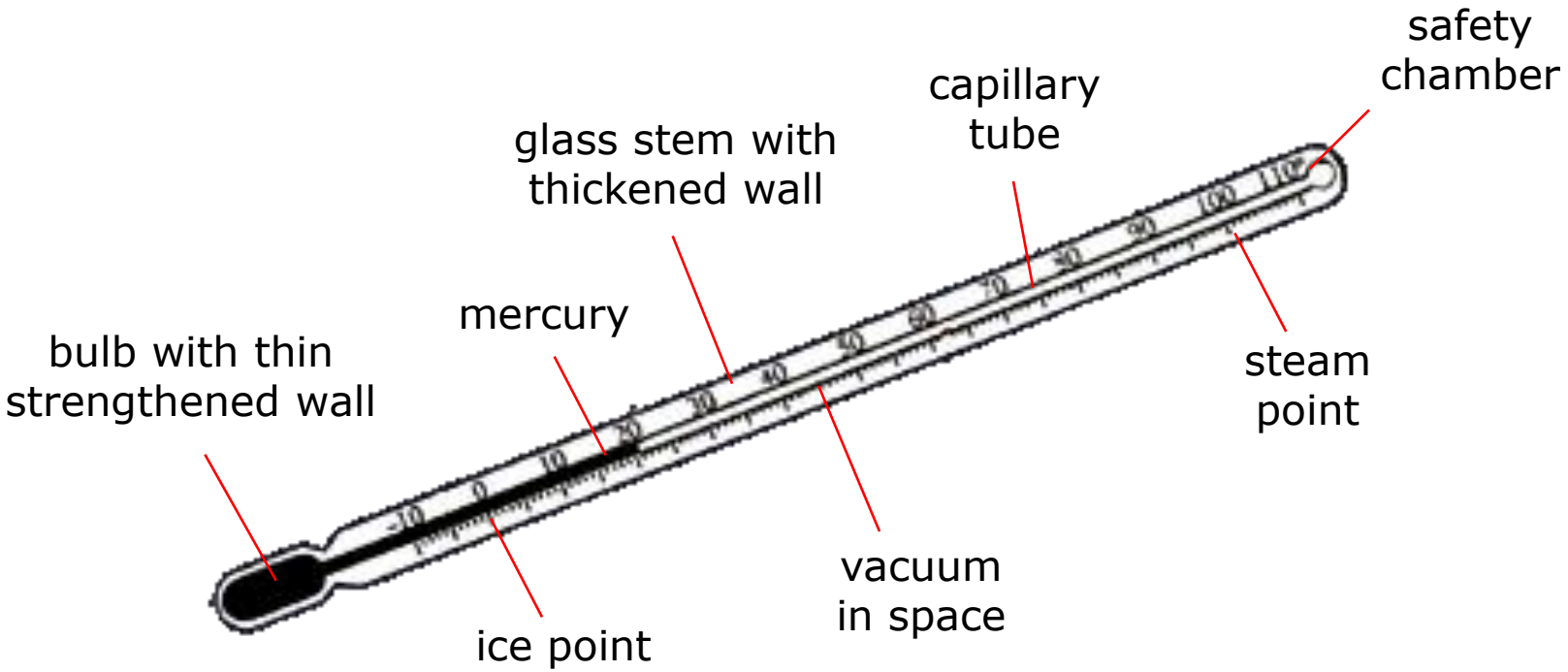
Example (b)

When l_θ is 3cm,

$$\theta = \frac{l_\theta - l_0}{l_{100} - l_0} \times 100 \ ^\circ\text{C}$$

$$\theta = \frac{3 - 8}{33 - 8} \times 100 = -20 \ ^\circ\text{C}$$

liquid-in-glass thermometers

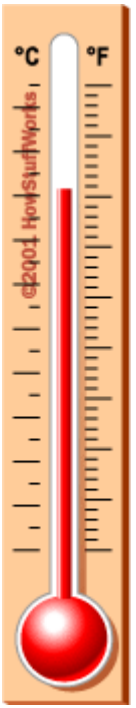


Laboratory Thermometer

Liquid-in-glass thermometers

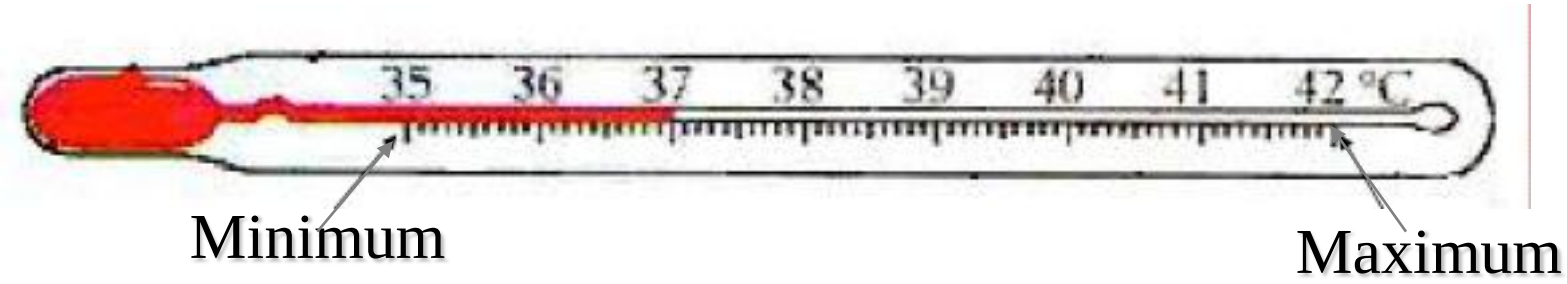
Characteristics:

- Range
- Sensitivity
- Responsiveness
- Linearity



Range

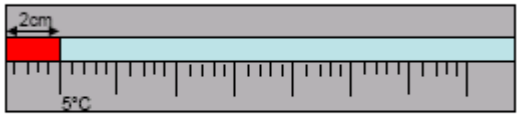
The range of thermometer is the interval between the minimum and maximum temperatures that it can measure.



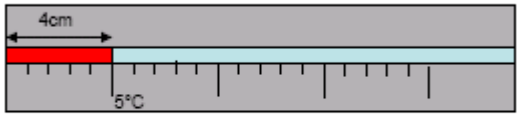
Range of clinical thermometer is 35°C –42°C

Sensitivity

The sensitivity of a mercury thermometer is defined as the change in length of mercury column per unit degree change in temperature (mm/ ℃)



Thermometer A



Thermometer B

Which thermometer is more sensitive? A or B

B is more sensitive

5 ℃ change results in a larger length of mercury column in B compared to A

Sensitivity

Sensitivity depends on:

1. Size of the glass bulb
   - Larger glass bulb increases the sensitivity

A larger bulb has more mercury for expansion to cause a big change in the length of the mercury thread than a smaller bulb for the same temperature

2. Size of the capillary tube
   - Narrower capillary tube increases the sensitivity

A small expansion of the mercury in the bulb will cause a bigger change in the length of the mercury thread of a narrower tube than a wider tube

Responsiveness

The responsiveness of a thermometer is the speed in which a reading can be obtained.

It depends on the thickness of the glass bulb.

A thin glass bulb is more responsive because heat takes less time to pass through a thin glass wall.

Linearity

Linearity measures the proportionality of change of the physical property with the temperature

A thermometer is linear if its temperature readings change proportionally with the length of the mercury column

Mercury is used in thermometer because it expands linearly with temperature

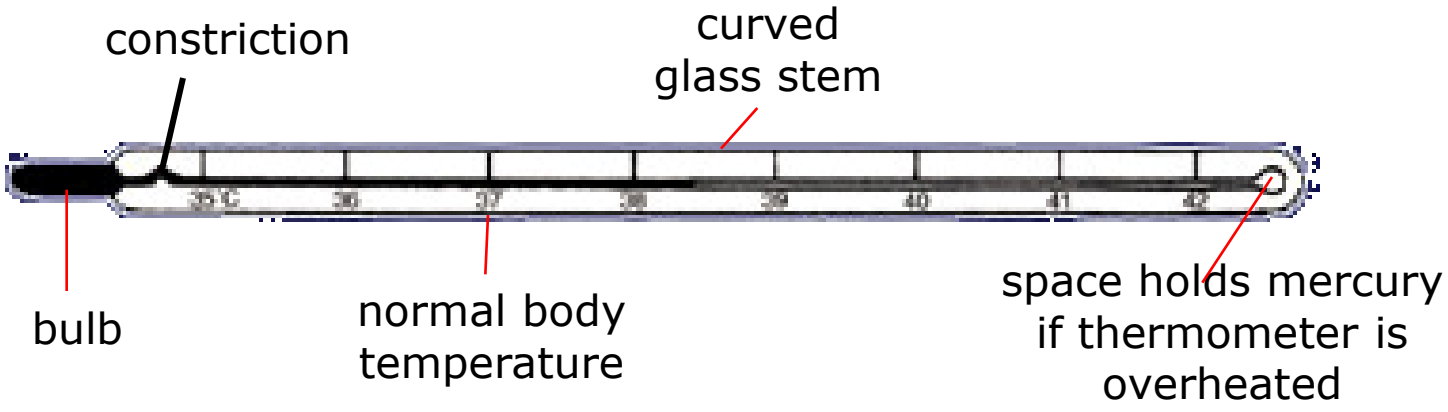
liquid-in-glass thermometers

Feature	Purpose
Mercury	Expands uniformly over a wide range of temperature.
Narrow bore of capillary tube	Makes the thermometer more sensitive
Bulb is made of thin glass	Heat can be conducted quickly to the mercury (responsive)
Round glass stem	Acts as a magnifying lens to make temperature reading easy.

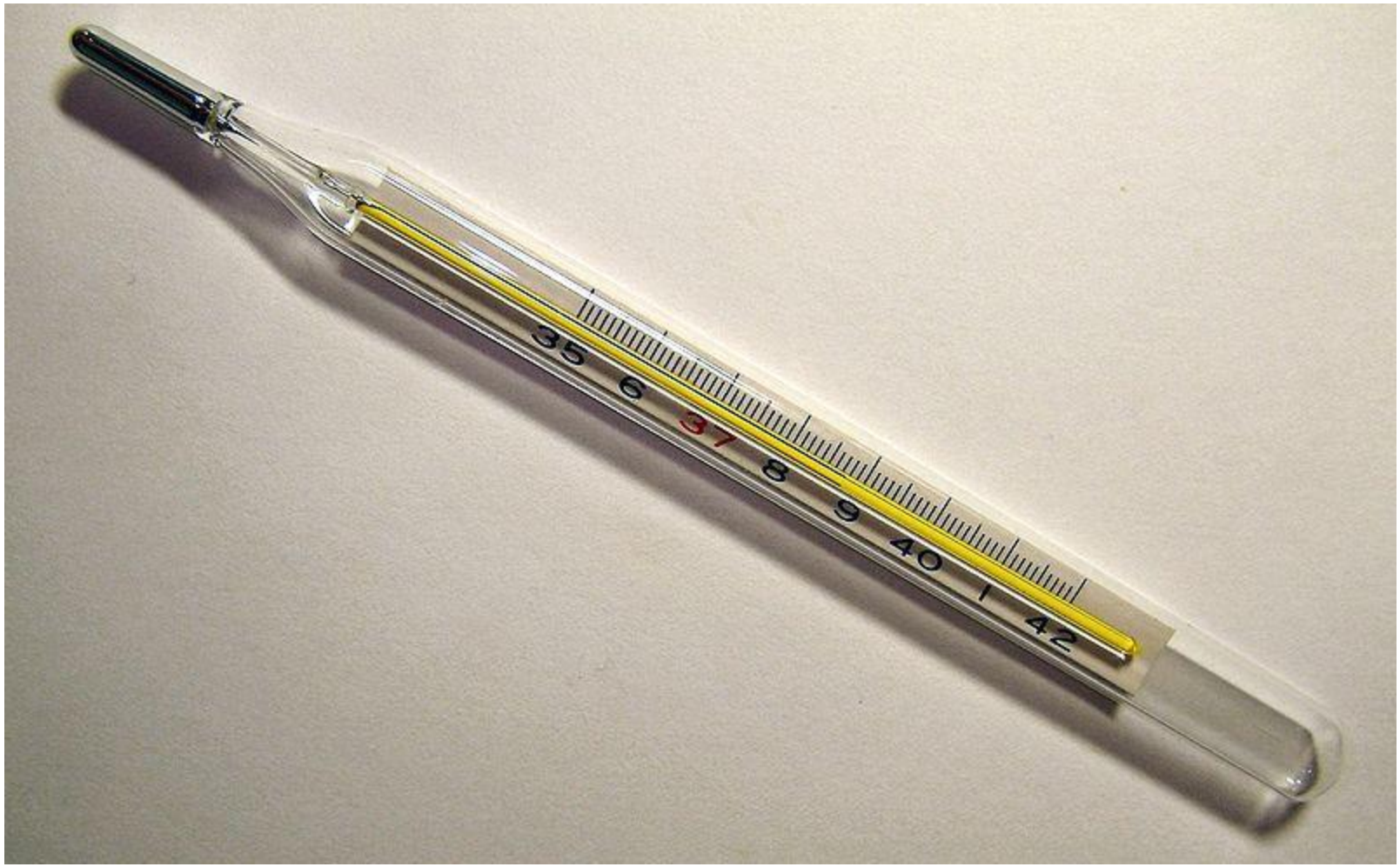
Clinical thermometers

- A thermometer specially designed for measuring the temperature of the human body.
- It is an ordinary mercury thermometer with two modifications:
  - short temperature range from about 35°C to 42°C
  - constriction in capillary tube just above the bulb of the thermometer

- The constriction prevents mercury from flowing back into the bulb by itself



Clinical thermometers



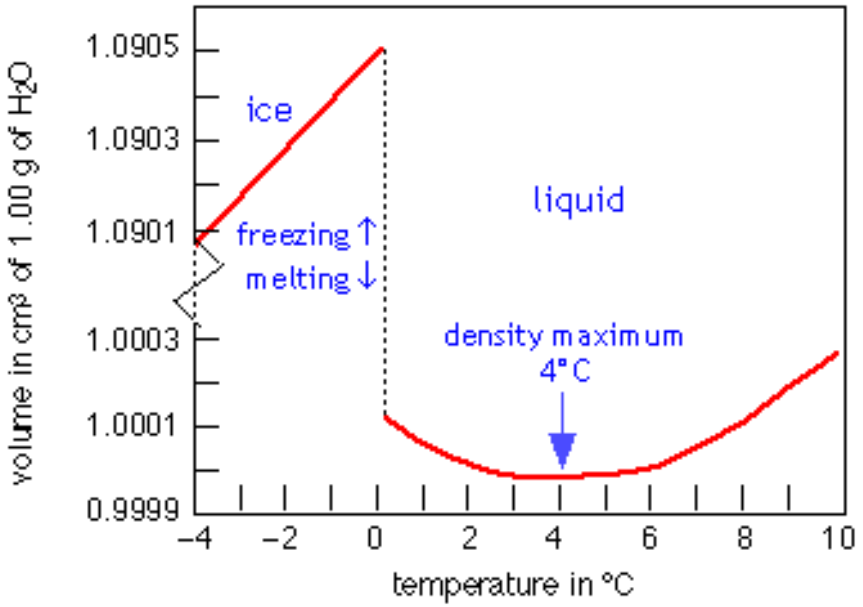
Checkpoint

Write down key characteristics of an ideal thermometer.

1. Larger glass bulb increases the sensitivity
2. Narrower capillary tube increases the sensitivity
3. Thin glass bulb increases responsiveness
4. Mercury gives linearity

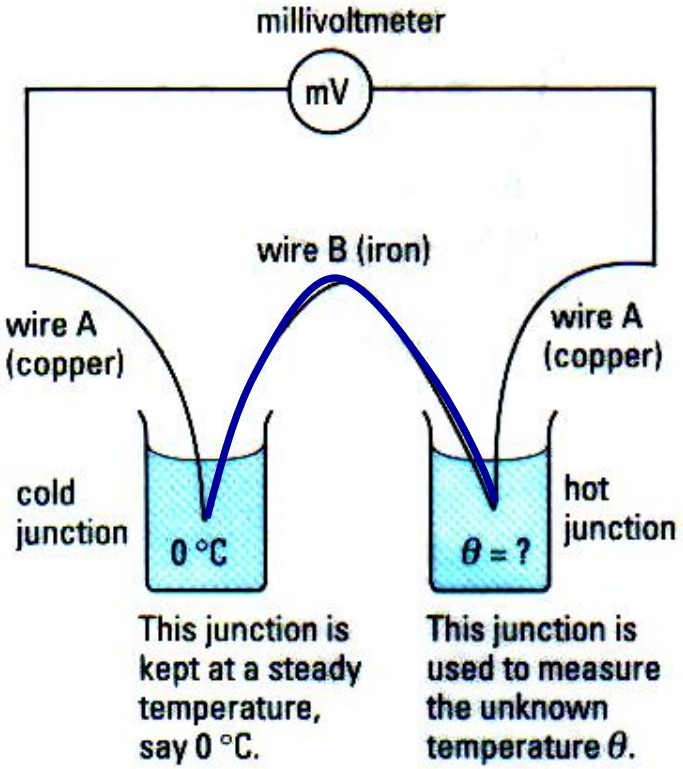
Why water cannot be used in liquid-in-glass thermometers

- Water doesn't expand or contract uniformly
- From 0 °C to 4 °C, water actually contracts instead of expanding.
- From 4 °C to 100 °C, water expands



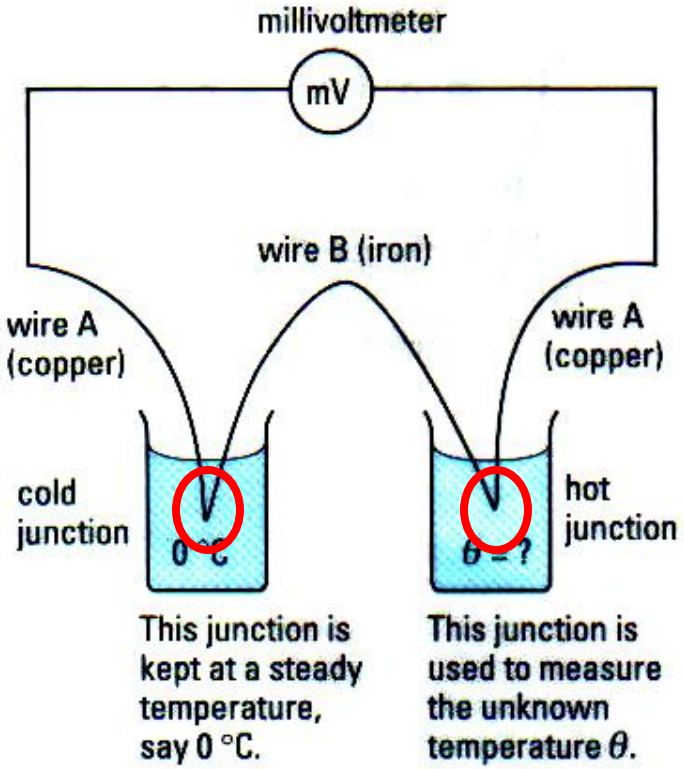
Thermocouple Thermometer

- Consists of two types of wires made of different metals such as copper and iron



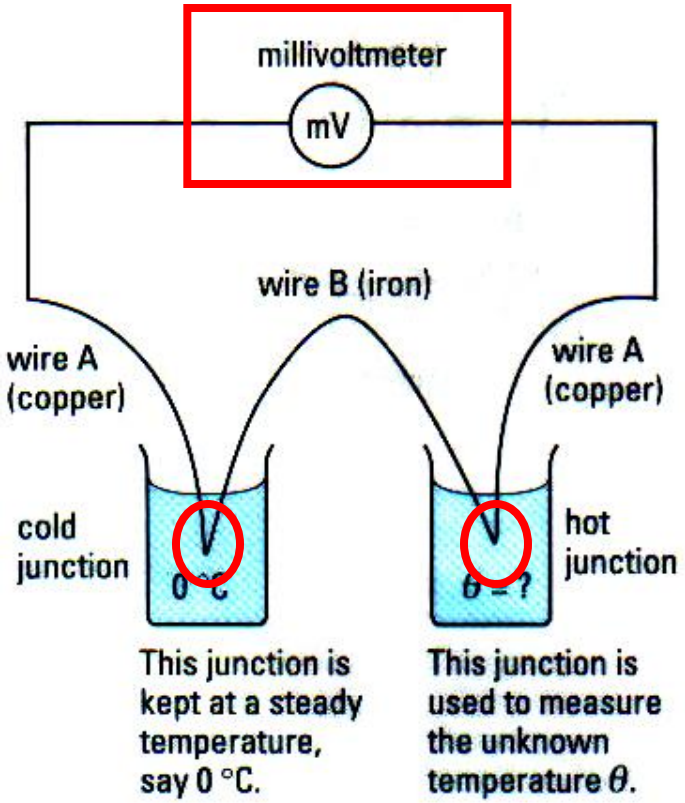
Thermocouple Thermometer

- The ends of the wires are joined together to form two junctions



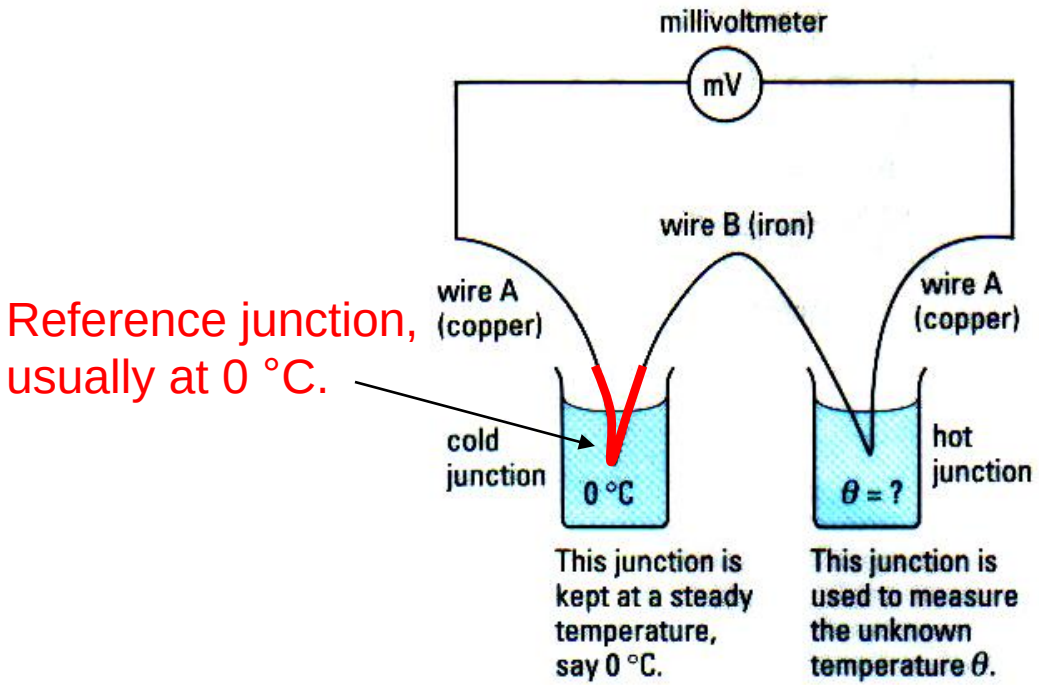
Thermocouple Thermometer

- Temperature is calculated using the readings of the voltmeter



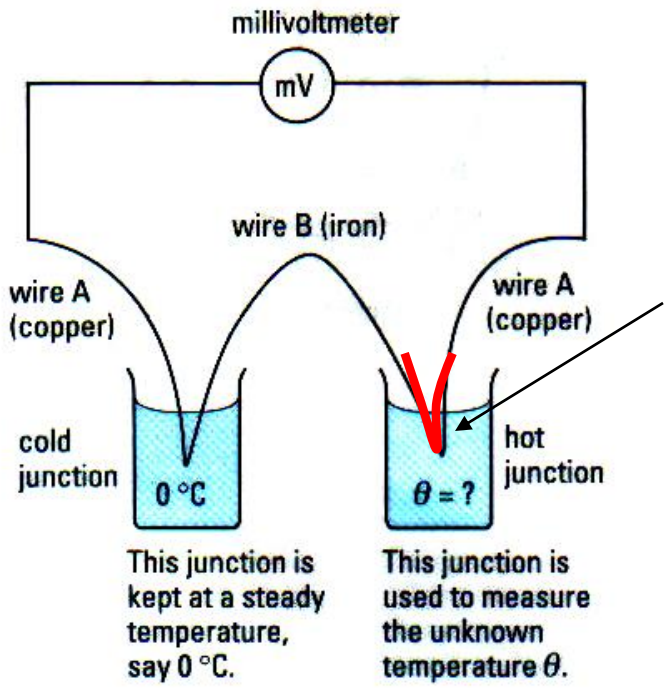
How does a thermocouple thermometer work?

- One junction is kept at a known temperature (e.g. 0 ˚C).
- This junction is known as the reference junction.



How does a thermocouple thermometer work?

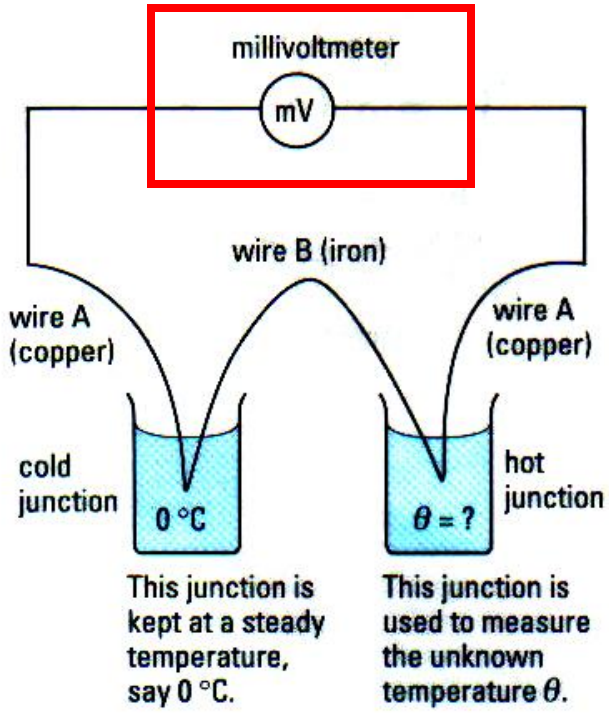
- The other junction, the probe tip, is used to measure the unknown temperature of other substances.



Probe tip to measure unknown temperature.

How does a thermocouple thermometer work?

- When the two junctions are at different temperatures, a small voltage (also known as electromotive force e.m.f.) is produced.



How does a thermocouple thermometer work?

- When the two junctions are at different temperatures, a small voltage (also known as electromotive force e.m.f.) is produced.

- Combining the information of the known reference temperature and the difference of temperature between the probe tip and the reference junction, the absolute temperature reading can be obtained.

Defining Equation of Thermocouple Thermometer

$$\varepsilon \propto \Delta\theta$$

where ε = e.m.f. produced

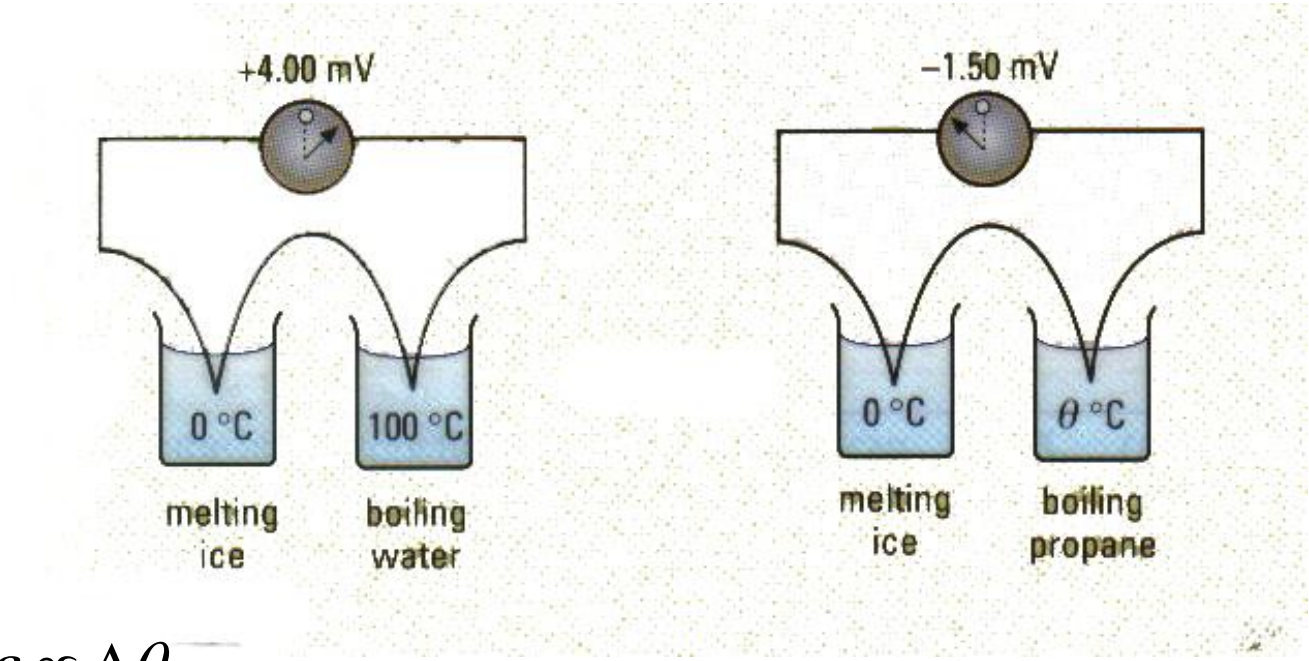
$\Delta\theta$ = temperature difference between the reference junction and the probe

By comparing the e.m.f. readings ε with a standard calibration table, we can then determine the unknown temperature.

Example

In a certain thermocouple thermometer, a voltage reading of +4.00 mV was obtained with one junction in melting ice and the other in boiling water at one standard atmosphere. When the hot junction was taken out of the boiling water and placed in boiling propane, the voltage registered was -1.50 mV. Find the temperature of the boiling propane on the Celsius scale of the thermocouple.

Example



Using $\varepsilon \propto \Delta\theta$,

4.00 mV $\propto$ (100 - 0) °C

and -1.50 mV $\propto$ (θ - 0) °C, where θ is the temperature of boiling propane.

Example

Using $\varepsilon \propto \Delta\theta$,

4.00 mV $\propto$ (100 - 0) °C

and -1.50 mV $\propto$ (θ - 0) °C, where θ is the temperature of boiling propane.

$$\Rightarrow \quad \frac{\theta - 0}{100 - 0} = \frac{-1.50}{4.00}$$

$$\therefore \quad \theta = \frac{-1.50}{4.00} \times 100 = -37.5°C$$

The temperature of the boiling propane is -37.5 °C.

Advantages of a Thermocouple Thermometer

- Robust, compact and fairly accurate
- Able to measure a very large temperature range of -200 °C to 1500 °C by choosing suitable types of metals for wires A and B.
- Very responsive to rapidly changing temperatures due to its small mass and because metals are good conductors of heat.
- As the output is an electrical signal (e.m.f. reading), it can be connected to suitable electrical equipment for checking rapid or sudden temperature changes.

Disadvantages of a Thermocouple Thermometer

- Low sensitivity, and its low voltage output may be masked by noise.
- Accuracy, usually no better than 0.5 °C, may not be high enough for some applications.
- Requires a known temperature reference, usually 0 °C ice water.
- Non-linearity could be bothersome.

http://en.wikipedia.org/wiki/Thermocouple

Thermocouple Thermometer

A thermocouple probe is inserted into the lava flow to measure the temperature