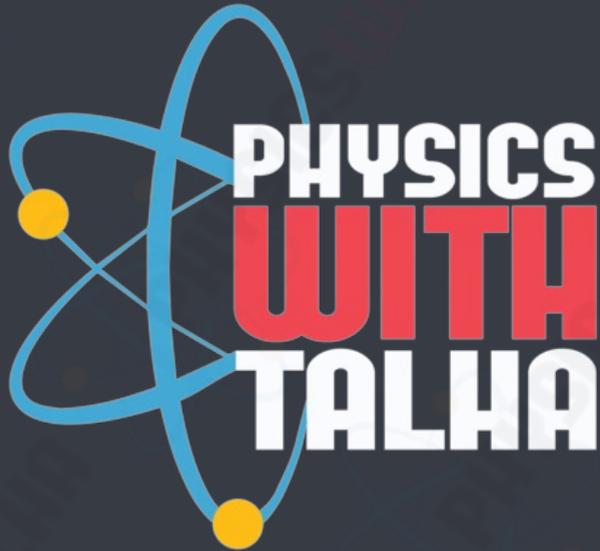


# Temperature

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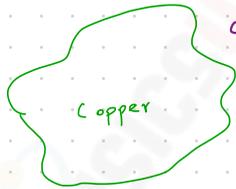
# Specific Heat Capacity

→ To raise the temperature of a substance, it needs to absorb thermal energy (heat)

→ For the temp. to drop, it needs to release thermal energy.



↑↑↑



↑↑↑

$c = 0.385$



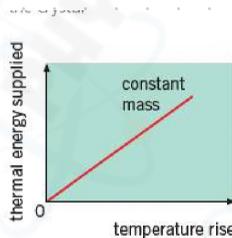
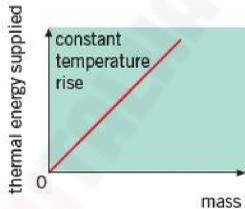
↑↑↑

$c = 0.129$



↑↑↑

→ The energy absorbed is proportional to  
(i) mass  
(ii) change in temp.



$$Q \propto m \quad (\Delta T \text{ constant})$$

$$Q \propto \Delta T \quad (m \text{ constant})$$

$$Q \propto m \Delta T$$

$$Q = c m \Delta T$$

$\rightarrow$  constant

Specific Heat Capacity (c) : " Energy absorbed or released to change the temperature of a substance by 1K (or 1°C) per unit mass of the substance "

$$c = \frac{Q}{m \Delta T}$$

Units:  $\text{J kg}^{-1} \text{ } ^\circ\text{C}^{-1}$

Annotations:  $Q \rightarrow \text{J}$ ,  $m \rightarrow \text{kg}$ ,  $\Delta T \rightarrow \text{ } ^\circ\text{C}$

$$c = \frac{Q}{m \Delta T}$$

Units:  $\text{J g}^{-1} \text{ } ^\circ\text{C}^{-1}$

Annotations:  $Q \rightarrow \text{J}$ ,  $m \rightarrow \text{g}$ ,  $\Delta T \rightarrow \text{ } ^\circ\text{C}$

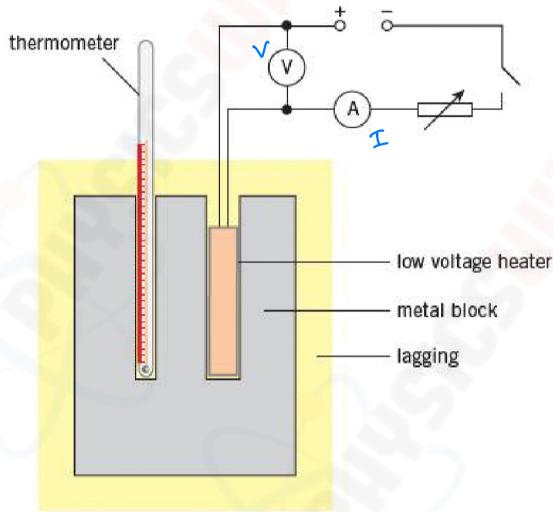
**Table 12.1** Values of specific heat capacity for different materials

material	specific heat capacity/ $\text{J kg}^{-1} \text{K}^{-1}$
ethanol	2500
glycerol	2420
ice	2100
mercury	140
water	4200
aluminium	913
copper	390
glass	640

→ coolant

$$Q = mc \Delta T$$

# How to determine the specific capacity of a solid



 stopwatch  
(t)

Electrical Energy  
supplied to heater

=

Thermal Energy  
absorbed by the  
metal.

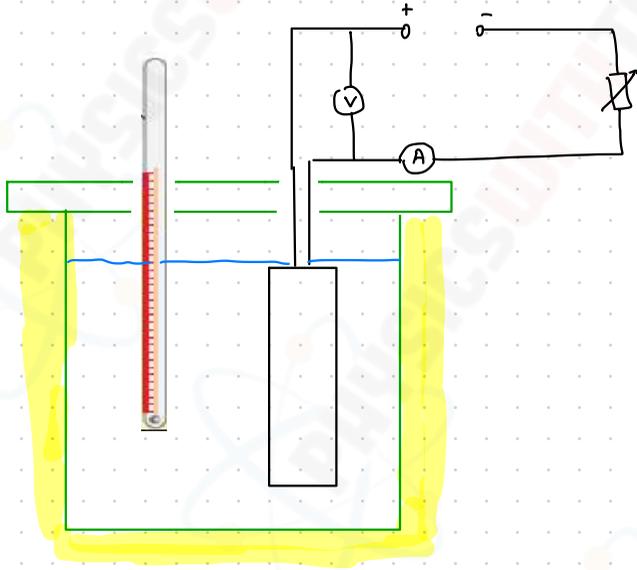
→ Assumption: No heat lost to the surroundings, no heat used by the other apparatus.

$$P t = m c \Delta T$$
$$(I V) t = m c \Delta T$$

↪ find.

# How to determine the specific capacity of a liquid

## Method 1



Electrical Energy supplied to heater = Thermal Energy absorbed by the liquid

→ Assumption: No heat lost to the surroundings, no heat used by the other apparatus.

$$P t = m c \Delta T$$
$$(I V) t = m c \Delta T$$

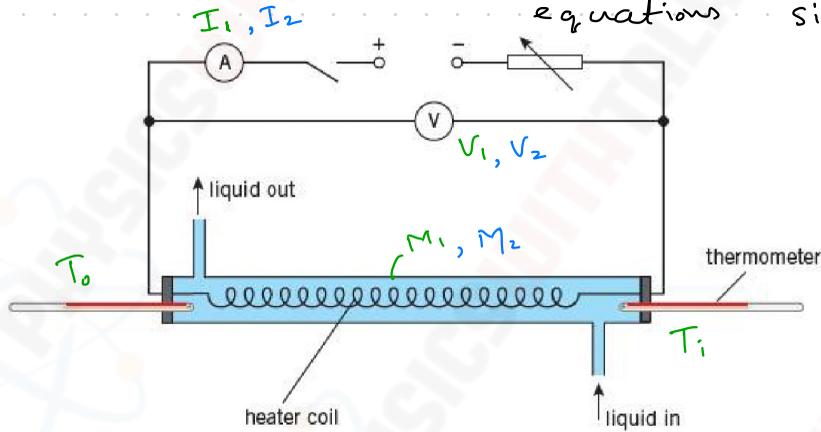
↪ find.

Not accurate because the assumption is not true.

(c will be more than the real value)

## Method 2

: Take two sets of readings and make two equations. Eliminate heat loss while solving the equations simultaneously.



①  $I_1, V_1$ , Mass ( $M_1$ ) of liquid collected in time ( $t$ )

$T_i, T_0$

Adjust the variable resistor to get diff. values of  $I$  and  $V$ . Then adjust the flow rate to get same values of  $T_i$  and  $T_0$ .

②  $I_2, V_2$ , mass ( $M_2$ ) of liquid collected in the same time ( $t$ ),

$T_i, T_0$

$$\begin{aligned} \text{Electrical energy supplied} &= \text{Thermal energy absorbed} + \text{heat lost} \\ \text{to the heater} & \text{by the liquid} \text{ to surroundings} \\ (I V t) &= [m c (T_o - T_i)] + h \end{aligned}$$

$$\rightarrow I_1 V_1 t = M_1 c (T_o - T_i) + h \quad \text{--- (1)}$$

$$\rightarrow I_2 V_2 t = M_2 c (T_o - T_i) + h \quad \text{--- (2)}$$

subtract (1) from (2)

$$[I_2 V_2 t - I_1 V_1 t] = [M_2 c (T_o - T_i) - M_1 c (T_o - T_i)] + [h - h]$$

$$(I_2 V_2 - I_1 V_1) t = (M_2 - M_1) c (T_o - T_i)$$

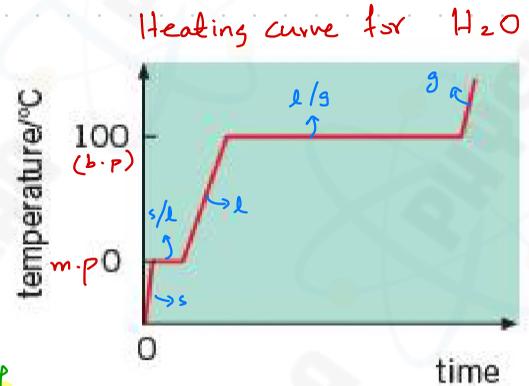
↪ find

## Specific Latent Heat (L)

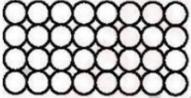
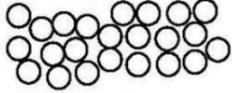
→ When heat is supplied at a constant rate to a solid its temp rises.

→ When it reaches the melting point, the temp stops rising, even though heat is being absorbed. Thermal energy is being used to break/weaken intermolecular forces and increase their spacing and hence the P.E. of particles. K.E. of particles remains constant during melting.

→ When all the solid has melted into the liquid, temp rises again until boiling point is reached. Again temp. remains constant even though heat is being supplied. Thermal energy is being used to break intermolecular forces and increase their spacing and hence the P.E. of particles. K.E. of particles remains constant during boiling.



Q: Why more energy is needed for boiling (latent heat of vapourisation) than melting (latent heat of fusion) for a substance?

Solids	Liquids	Gases
		

→ The energy needed to completely separate the particles and overcome intermolecular forces is much greater than energy needed to break rigid bonds during melting. The change in spacing during boiling is much more significant.

→ Moreover, energy is also needed to do work against the atmospheric pressure as volume of gas increases.

Specific latent heat of **fusion**:

"the numerical value of specific latent heat of fusion is equal to the quantity of heat energy needed to **melt a solid of unit mass**, without a change in temperature"

Specific latent heat of **vaporization**:

"the numerical value of specific latent heat of vaporization is equal to the quantity of heat energy needed to **boil a liquid of unit mass**, without a change in temperature"

During melting and boiling, the object absorbs latent heat

During **condensation** and **freezing**, the object loses latent heat

Table 12.2 Values of specific latent heat

material	specific latent heat of fusion/ $\text{kJ kg}^{-1}$	specific latent heat of vapourisation/ $\text{kJ kg}^{-1}$
ice/water	330	2260
ethanol	108	840
copper	205	4840
sulfur	38.1	

$$Q = m l$$

$$l = \frac{Q}{m}$$

Annotations:  $\text{J g}^{-1}$  with an arrow pointing to  $l$ ;  $\text{J}$  with an arrow pointing to  $Q$ ;  $\text{g}$  with an arrow pointing to  $m$ .

$$l = \frac{Q}{m}$$

Annotations:  $\text{J kg}^{-1}$  with an arrow pointing to  $l$ ;  $\text{J}$  with an arrow pointing to  $Q$ ;  $\text{kg}$  with an arrow pointing to  $m$ .

## How to determine the $l_f$ of ice

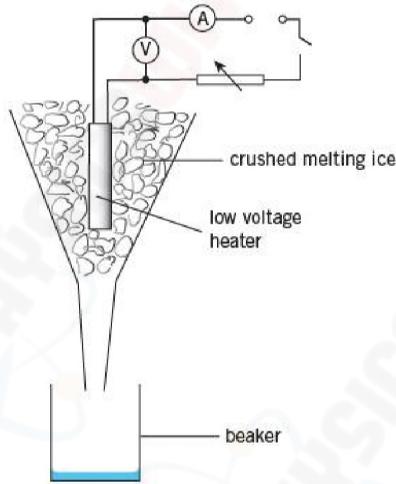


Figure 12.8 Apparatus to determine the latent heat of fusion of ice.

- We wait until ice starts dripping at a **constant rate**
- Now place a **weighed beaker** on balance and place them under the funnel. Collect the water for **time t**. Record the **mass m** collected.
- **This is the mass that melts in time t just due to the energy absorbed from the surroundings.**
- Switch heater on and keep current constant
- Wait for water to drip at a **constant rate**
- Now measure the **mass M** collected in the **same time t**
- Readings **V** and **I** are also recorded

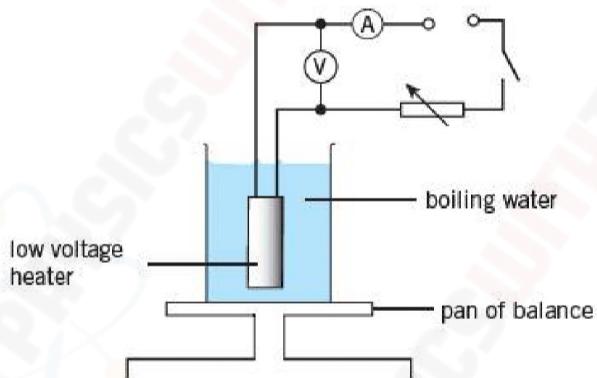
Energy supplied by heater + energy from surrounding to melt ice. = Total energy used to melt ice with heater + surroundings.

$$P \times t + m l_f = M l_f$$

$$I V t + m l_f = M l_f$$

$$I V t = (M - m) l_f \rightarrow \text{find}$$

## How to determine the $l_v$ of water



- Heater is **switched on** and current is kept constant
- When mass begins to reduce at a **constant rate** record the **mass  $M_1$**  that changed in a certain time interval  **$t$**
- Also record the readings  **$I_1$**  and  **$V_1$**
- Now **change** the value of **current** and **voltage**
- Record these new values  **$I_2$**  and  **$V_2$**
- Wait for the **mass to decrease** at a **constant rate**
- Record the **mass  $M_2$**  in the same time interval  **$t$**

Energy supplied by heater = energy used to boil water + energy lost to surroundings

$$I_1 V_1 t = M_1 l_v + h \rightarrow (1)$$

$$I_2 V_2 t = M_2 l_v + h \rightarrow (2)$$

Subtract

$$(I_2 V_2 - I_1 V_1) t = (M_2 - M_1) l_v \rightarrow \text{find}$$

- 1) Calculate the quantity of heat energy required to raise the temperature of a mass of 810g of aluminium from 20°C to 75°C. The specific heat capacity of aluminium is 910 J kg<sup>-1</sup> K<sup>-1</sup>.

$$Q = mc \Delta T = (0.810)(910)(75 - 20) = 4.1 \times 10^4 \text{ J}$$

- 2) Calculate the heat energy gained or lost for the following temperature changes. Use Table 12.1 to obtain values for specific heat capacity.

(a) 45g of copper heated from 10°C to 90°C

(b) 1.3g of ice at 0°C cooled to -15°C.

$$a) Q = 0.045 \times 390 \times (90 - 10) = 1404 \text{ J} \quad \text{gained}$$

$$b) Q = (1.3 \times 10^{-3}) (2100) (15) = 40.95 \text{ J} \quad \text{lost}$$

- 3) Calculate the specific heat capacity of water given that 0.20 MJ of energy are required to raise the temperature of a mass of 600g of water by 80K.

$$c = \frac{Q}{m \Delta T} = \frac{0.20 \times 10^6}{0.6 \times 80} = 4.2 \times 10^3 \text{ J kg}^{-1} \text{ K}^{-1}$$

Table 12.1 Values of specific heat capacity for different materials

material	specific heat capacity/J kg <sup>-1</sup> K <sup>-1</sup>
ethanol	2500
glycerol	2420
ice	2100
mercury	140
water	4200
aluminium	913
copper	390
glass	640

4) A kettle contains 700g of water. The specific heat capacity of water is  $4200 \text{ J kg}^{-1} \text{ K}^{-1}$  and the kettle itself has heat capacity  $540 \text{ J K}^{-1}$ . The kettle and its contents are heated from  $15^\circ\text{C}$  to the boiling point of water ( $100^\circ\text{C}$ ).

(a) Calculate the heat energy gained by:

- (i) the water,
- (ii) the kettle.

(b) What fraction of the total energy was used in heating the water?

$$(a) (i) Q = mc\Delta T = 0.7 \times 4200 \times (100 - 15) = 249900 \text{ J}$$

$$(ii) Q = C\Delta T = 540 \times (100 - 15) = 45900 \text{ J}$$

$$(b) \frac{249900}{249900 + 45900} \times 100 = 85 \%$$

5) Where appropriate, use the information given in Table 12.2.

(a) Calculate the heat energy required to:

- (i) melt 50g of ice at  $0^\circ\text{C}$ ,
- (ii) evaporate 50g of water at  $100^\circ\text{C}$ .

(b) Using your answers to a, determine how many times more energy is required to evaporate a mass of water than to melt the same mass of ice.

$$a) (i) Q = ml_f = (0.050) (330 \times 10^3) = 16500 \text{ J}$$

$$(ii) Q = ml_v = (0.050) (2260 \times 10^3) = 113000 \text{ J}$$

$$(b) \frac{113000}{16500} = 6.8 \text{ times}$$

Table 12.2 Values of specific latent heat

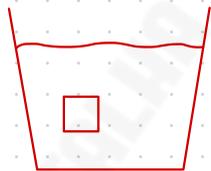
material	specific latent heat of fusion/ $\text{kJ kg}^{-1}$	specific latent heat of vaporisation/ $\text{kJ kg}^{-1}$
ice/water	330	2260
ethanol	108	840
copper	205	4840
sulfur	38.1	

- 6) A mass of 0.30 kg of water at 95°C is mixed with 0.50 kg of water at 20°C. Calculate the final temperature of the water, given that the specific heat capacity of water is 4200 J kg<sup>-1</sup> K<sup>-1</sup>. → T

Hint: always start by writing out a word equation containing all the gains and losses of heat energy.

$$\begin{aligned}
 \text{Energy released by} &= \text{Energy absorbed by} \\
 \text{0.30 kg of water} &= \text{0.50 kg of water} \\
 m_1 c \Delta T_1 &= m_2 c \Delta T_2 \\
 (0.30)(4200)(95 - T) &= (0.50)(4200)(T - 20) \\
 T &= 48^\circ\text{C}
 \end{aligned}$$

- 7) A mass of 12 g of ice at 0°C is placed in a drink of mass 210 g at 25°C. Calculate the final temperature of the drink, given that the specific latent heat of fusion of ice is 334 kJ kg<sup>-1</sup> and that the specific heat capacity of water and the drink is 4.2 kJ kg<sup>-1</sup> K<sup>-1</sup>.

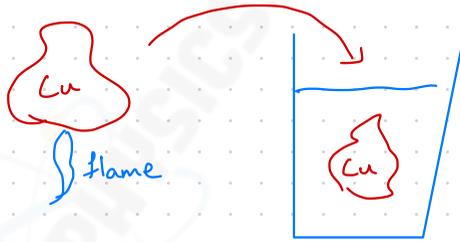


$$\begin{aligned}
 \text{Energy absorbed} &+ \text{Energy absorbed} &= \text{Energy released} \\
 \text{by melting ice} &+ \text{by cold water} &= \text{by warm water} \\
 (m_i l_f) &+ m_c c (T - 0) &= m_d c (25 - T) \\
 (0.012 \times 334000) &+ 0.012 \times 4200 \times T &= 0.210 \times 4200 \times (25 - T) \\
 4008 &+ 50.4 T &= 22050 - 882 T \\
 T &= 19^\circ\text{C}
 \end{aligned}$$

**Table 12.1** Values of specific heat capacity for different materials

material	specific heat capacity / J kg <sup>-1</sup> K <sup>-1</sup>
ethanol	2500
glycerol	2420
ice	2100
mercury	140
water	4200
aluminium	913
copper	390
glass	640

- b) A lump of copper of mass 120g is heated in a gas flame. It is then transferred to a mass of 450g of water, initially at 20°C. The final temperature of the copper and the water is 31°C. Calculate the temperature of the gas flame. → initial copper temp.



Energy released by copper = Energy gained by water

$$0.120 \times 390 \times (T - 31) = 0.450 \times 4200 \times (31 - 20)$$

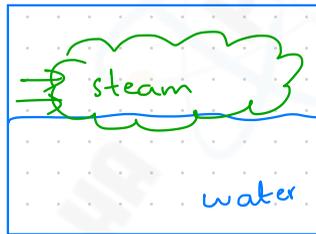
$$46.8 T - 1450.8 = 20790$$

$$475^\circ\text{C} = T$$

**Table 12.2** Values of specific latent heat

material	specific latent heat of fusion / kJ kg <sup>-1</sup>	specific latent heat of vaporisation / kJ kg <sup>-1</sup>
ice/water	330	2260
ethanol	108	840
copper	205	4840
sulfur	38.1	

- a) Steam at 100°C is passed into a mass of 350g of water, initially at 15°C. The steam condenses. Calculate the mass of steam required to raise the temperature of the water to 80°C.



Energy released by steam condensing + Energy released by hot water = Energy absorbed by cold water

$$m_s L_v + m_s c (100 - 80) = m_w c (80 - 15)$$

$$m_s \times 2260 + m_s \times 4200 \times 20 = 0.350 \times 4200 \times 65$$

$$m_s = 0.041 \text{ kg}$$

# Thermal equilibrium and the zeroth law of thermodynamics

- If two bodies at different temperatures are in thermal contact with each other, heat (transfer of thermal energy) would flow from hot body to the cold body.
- The temperature of two bodies eventually becomes equal.
- Bodies at equal temperatures are said to be in thermal equilibrium.

## Thermal equilibrium:

"When bodies are in thermal equilibrium, their temperatures are equal and there is no net heat transfer between the bodies."



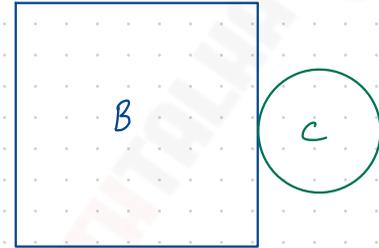
How do we measure the hotness/coldness of a body? What should be the units used?

We measure it with a thermometer and the quantity that tell us how hot or cold something is called temperature.

**Zerth law of thermodynamics:**

"If body A is in thermal equilibrium with body C and body B is in thermal equilibrium with body C, then body A and body B must be in thermal equilibrium with each other."

This law may seem like a logical after thought but it is the law that is fundamental to our understanding of the temperature and our trust in the process of measuring the temperature of different bodies with a thermometer. The 3rd body C in the law can be thought of as your thermometer.



# What is Temperature

Lets suppose for a moment that you have no concept of a quantity called temperature. You only have general sense of hotness and coldness because of how objects feel when you touch them. If you decided to quantify the hotness/coldness of objects how will you measure it?

To make temperature scale you need 3 things:

1. A thermometric property ✓
2. Two fixed points ✓
3. A numerical scale ✓

We observe that other properties of objects vary as they get hotter or colder. Examples of such properties are:

- Length of a metal rod ✗
- Volume of a gas or a liquid
- Length of a liquid column in a capillary tube (very narrow tube)
- Resistance of coil of wire
- E.m.f produced between hot and cold junctions made by joining together wires of 2 different metals.

Such properties are called **thermometric properties**. Every thermometer measures the change in one of these properties in order to measure the change in temperature.

It is an advantage if:

- Thermometric property varies linearly with temperature, but most of the time that is not the case
- A small change in temperature should produce a large change in the property to allow for precise measurements
- The nature of relationship should remain similar over a large range of temperatures

A **fixed point** is any temperature where all thermometers gives the same reading even they are using different thermometric properties.

They should be:

- Easily reproducible ✓
- Precisely reproduced ✓

Common examples of fixed points are ice point and steam point. There are other as well which are actually more precise and more useful.

- ✓ • **Ice point:** the temperature where pure ice and pure water are in thermal equilibrium at standard atmospheric pressure. Obtained in lab by having a mixture of ice and water. It is  $0^{\circ}\text{C}$  in Celsius or centigrade scale. We gave it this value ourselves, there is nothing special about the number zero.
- ✓ • **Steam point:** the temperature at which pure water and vapour are in thermal equilibrium at standard atmospheric pressure. It is  $100^{\circ}\text{C}$  in Celsius or centigrade scale. We gave it this value ourselves, there is nothing special about the number one hundred.

To make a sensible scale for temperature you need to measure the property at two fixed points and than divide the scale into a sensible number of divisions (say 100) so you can use that scale to measure the temperature of any object. Now you have numerical values on your scale.

# Empirical scales of temperature

**Empirical scale** means a scale based on experimental results. They rely on some thermometric property of a substance.

Let  $X$  be a thermometric property.

$X$  could be anything like length, pressure, volume, resistance, E.m.f, etc. Choose two fixed points, for example:

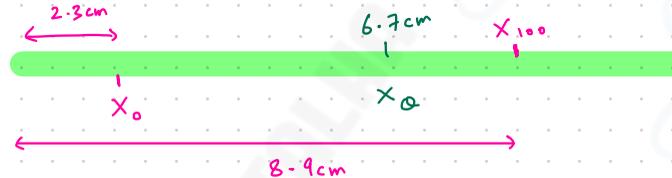
- Ice point: lets call it 0
- Steam point: lets call it 100

Let;

$X_0$  = value of thermometric property at ice point = 2.3cm

$X_{100}$  = value of thermometric property at steam point = 8.9cm

$X_\theta$  = value of thermometric property at unknown temperature  $\theta$  that you want to measure. = 6.7cm



The following expression could help us calculate  $\theta$ :

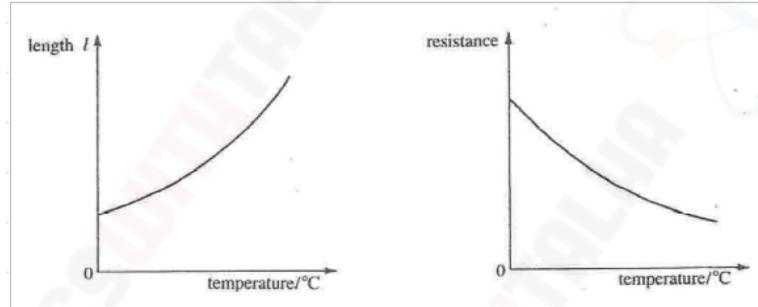
$$\theta = \frac{X_\theta - X_0}{X_{100} - X_0} \times \text{difference of two fixed points} + \text{lower fixed point}$$

We gave our fixed points values of 0 and 100 so difference between them is 100. Cent comes of hundred so we call this the centigrade scale or Celsius scale. The formula becomes:

$$\theta = \frac{X_\theta - X_0}{X_{100} - X_0} \times 100^\circ\text{C} = \frac{6.7 - 2.3}{8.9 - 2.3} \times 100 = 67^\circ\text{C}$$

Note that we are assuming property X varies linearly with temperature.

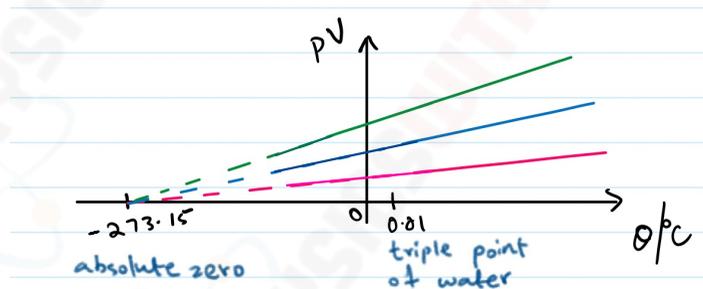
In reality, most properties do not vary linearly, for example length of a thread of mercury or resistance of a thermistor.



For designing different thermometers if chose the same fixed points (ice point and steam point), then they will agree at fixed point but it is unlikely that they will agree at other temperatures. This is the problem with empirical scales.

# Thermodynamic scale of temperature

- Thermodynamic scale is not an empirical scale. It is not based on the thermometric property of any material.
- This scale is based on properties of ideal gas. Ideal gas is not a real material, it's a theoretical model of gases which obey the equation  $PV=nRT$ .
- We know that the product of pressure and volume,  $pV$ , varies linearly with temperature. So this is what we will use to define the thermodynamic scale.
- The thermometer we use for this purpose is called a **constant-volume gas thermometer**. It could have any real gas in it like nitrogen, hydrogen, helium, etc.
- A graph of  $pV$  vs  $\theta$  ( $^{\circ}\text{C}$ ) is drawn. The line is straight.

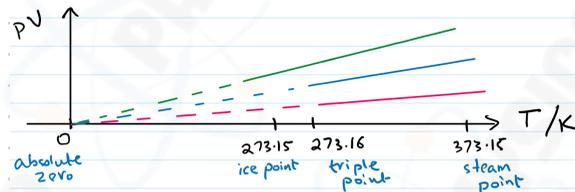


- When the experiment is repeated with smaller and smaller amounts of gas so that pressure is as low as possible. This is because real gases approach behaviour of ideal gas when the pressure is very low. The experiment can also be repeated with different gases.
- When we **extrapolate** all the lines they all converge at  $-273.15$ . There must be something special about this temperature.

- $-273.15\text{ }^{\circ}\text{C}$  is called **absolute zero**. At this temperature it is suggested that there can be no more energy removed from the gas and this is the lowest possible temperature. The particles have lowest possible energy. Clearly our new scale should use this point as its zero, it is taken as **one of the fixed points** of the scale.
- The **other fixed point** used to make our scale is **triple point of water**. The temperature and pressure at which ice, water and steam are in thermal equilibrium and all three can coexist. This is much more reliably and precisely reproduced than melting and boiling point of water. In centigrade or Celsius scale the triple of water is fixed as  $0.01\text{ }^{\circ}\text{C}$  or  $273.16\text{ K}$  in thermodynamic scale by international agreement. This value of  $273.16$  is chosen so that the difference between ice point and steam point will be exactly  $100\text{ K}$ . So Celsius scale and Kelvin scale both have same size of the unit.
- After shifting the zero to absolute zero we have the thermodynamic scale and its temperature is measured in **kelvins (K)**. The value of triple of water is chosen in such a way that change of  $1\text{ K}$  is equal to change of  $1\text{ }^{\circ}\text{C}$ , but the scales are shifted  $273.15$  units away from each other.
- **Definition of kelvin:** One kelvin ( $1\text{ K}$ ) is  $1/273.16$  of the triple point of water on thermodynamic scale.
- If a constant-volume gas thermometer gives the pressure as  $p_{tr}$  at triple point of water and then gives the pressure as  $p$  at some unknown temperature. Then it can be calculated in kelvin using:

$$T = 273.16 \left( \frac{p}{p_{tr}} \right)$$

- The equation is more and more accurate if a smaller amount of gas is used in the thermometer.



Fixed point	Definition	Thermodynamic temperature T/K	Degree Celsius temperature 0/°C
Absolute zero		0	-273.15
Triple point of water		273.16	0.01
Ice point		273.15	0.00
Steam point		373.15	100.00

The table should clear any confusion you may have about various temperatures mentioned in this chapter.

How to convert temperature in °C to K:

$$T/K = \theta/^{\circ}\text{C} + 273.15$$

But remember to give your answer correct to an appropriate number of decimal places.

$$\begin{aligned}
 93^{\circ}\text{C} &\longrightarrow \text{K} \\
 93 + 273.15 \\
 &= 366.15 \text{ K} \\
 &\approx 366 \text{ K}
 \end{aligned}$$

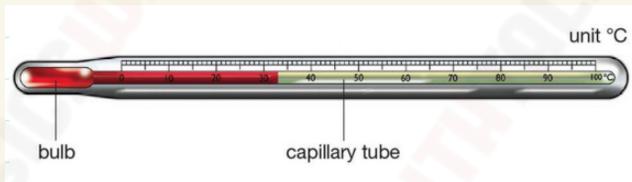
$$\begin{aligned}
 2.3457^{\circ}\text{C} &\longrightarrow \text{K} \\
 2.3457 + 273.15 \\
 &= 275.4957 \text{ K} \\
 &\approx 275.50 \text{ K}
 \end{aligned}$$

# Types of thermometers

Factors that determine the choice of thermometer:

- Range
- Sensitivity
- Linearity
- Accuracy
- Responsiveness
- Robustness
- Remote measurement

## 1) Liquid in glass thermometer (mercury or alcohol)



Range for mercury :  $-39\text{ }^{\circ}\text{C}$  to  $357\text{ }^{\circ}\text{C}$  Range for alcohol:  $-200\text{ }^{\circ}\text{C}$  to  $78\text{ }^{\circ}\text{C}$

Sensitivity depends on how narrow the tube is and how much liquid is used in the bulb. They are sensitive enough that readings are precise enough for clinical and routine laboratory measurements. But there more precise options available.

Accuracy depends on size of the bulb. Bigger bulb means less accurate value because the bulb will itself absorb too much heat from the substance and the reading shown will slightly less than the actual value.

Expansion of mercury almost linear with temperature.

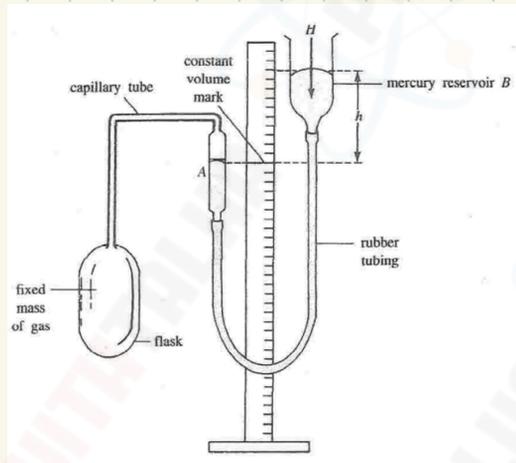
Their scale is very close to the thermodynamic scale over their range. Convenient and easy to use

Also very portable

Gives reading fairly quickly but does not give the reading instantly They can be broken easily

Cannot measure very high temperatures

## 2) Constant volume gas thermometers



They are certainly important for establishing the link between the empirical centigrade scale and the thermodynamic scale of temperatures.

But they bulb containing gas is large so they cannot measure temperatures of small objects  
They are bulky and inconvenient to use for quick measurements and measurements outside of the lab

They can be very sensitive They are linear

They are accurate

They have a large range, but it depends on the liquification temperature of the gas being used  
Since they are standard for all other thermometers, other types of thermometers are calibrated using these

### 3) Resistance thermometers

They can use a coil of wire, whose resistance increases with temperature. Platinum is commonly used.

Their range can be very wide, from  $-260\text{ }^{\circ}\text{C}$  to  $1700\text{ }^{\circ}\text{C}$

The variation of resistance is not linear over the very wide range but for a small range a can be considered as linear.

Not good measuring quickly changing temperatures as it takes time for wire to attain thermal equilibrium with surroundings because of its large thermal capacity

They are quite accurate

Very robust

Their sensitivity is less than thermistor resistance thermometers

Can be used to measure temperature remotely with the help of long conducting wires They are digital so they can be connected to a computer to record values

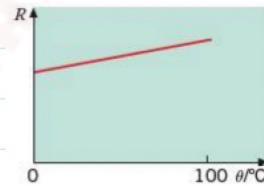
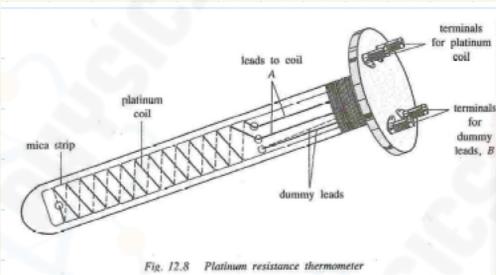


Figure 11.6 Resistance  $R$  of a metal wire over a small range of temperatures



Figure 11.7 Thermistors are useful temperature measuring devices

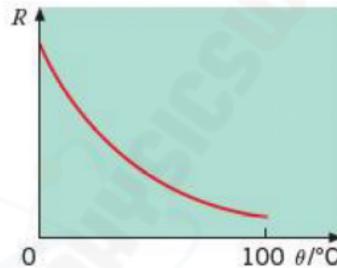


Figure 11.8 Resistance  $R$  of a thermistor over a small range of temperatures

Or they can use a thermistor whose resistance decreases very rapidly with temperature  
Because of rapid change they are very sensitive  
But their variation is not linear with temperature. Their range is narrow because of this non-linearity

Small size of the sensor allows for measurement of temperature of very small objects Can be used to measure temperature remotely with the help of long conducting wires They are digital so they can be connected to a computer to record values

#### 4) Thermocouple thermometers

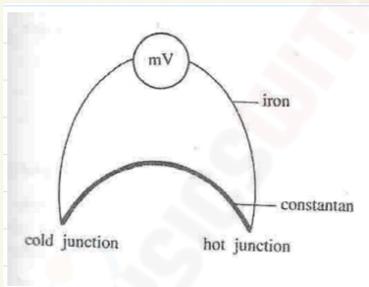


Figure 11.11 Thermocouple thermometer.

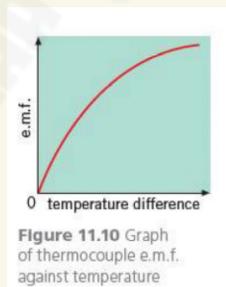


Figure 11.10 Graph of thermocouple e.m.f. against temperature

When there is a temperature difference between two junctions, a small E.m.f is produced. Its called the thermoelectric effect.

They are also very robust

Their range can be very wide: from  $-250^{\circ}\text{C}$  to  $1150^{\circ}\text{C}$

Their sensor is even smaller than resistance thermometers so they can measure temperatures of very small objects

Can be used to measure temperature remotely with the help of long conducting wires Correct choice of metals will make a very sensitive thermometer

The variation is non-linear so requires calibration

They are very good for measuring rapidly changing temperatures

They are digital so they can be connected to a computer to record values

# Comparison of Resistance and Thermocouple thermometers

Feature	Resistance thermometer	Thermocouple thermometer
robustness	very robust	robust
range	thermistor: narrow range resistance wire: wide range	can be very wide
size	larger than thermocouple, has greater thermal capacity therefore slower acting	smaller than resistance thermometers, has smaller thermal capacity, so quicker acting and can measure temperature at a point
sensitivity	thermistor: high sensitivity over narrow range resistance wire: less sensitive	can be sensitive if appropriate metals chosen
linearity	thermistor: fairly linear over narrow range resistance wire: good linearity	non-linear so requires calibration
remote operation	long conducting wires allow the operator to be at a distance from the thermometer	long conducting wires allow the operator to be at a distance from the thermometer