

THERMAL PHYSICS

Temperature

- * A thermometer shows you its own temperature.
- * Energy is transferred from a hotter object to a cooler. \therefore the reading of the thermometer rises as it absorbs energy from its surroundings.
- * When two objects are of the same temperature, there is no transfer of energy between them. \therefore The reading stabilises and the thermometer bulb is at the same temperature as its environment.
- ⊕ Energy flowing from a region of higher temperature to a region of lower temperature is called Thermal Energy. The mechanism could be conduction, convection or radiation.
- ⊕ When two objects, in contact with each other, are at the same temperature, there will be no transfer of thermal energy between them. They are said to be in thermal equilibrium.
- * Celsius scale of temperature takes 2 fixed points — melting pt. of pure ^{ice} water and boiling point of pure water — and divides the range between them into 100 equal intervals. Both fixed points change if the pressure changes or if the water/ice is impure.
- * The thermodynamic scale aka Kelvin scale is a better scale in that one of its fixed points, absolute zero, has a greater significance than either of the Celsius fixed points.
- * Absolute zero = 0K — no lower temp possible.
for any matter at absolute zero, it is impossible to remove any more energy from it. \therefore It is the temperature at which all substances have the minimum internal energy (i.e. K.E. of atoms/molecules is zero & the electrical P.E. is minimum.)
- * θ = Celsius scale T = Kelvin scale
 $\theta = T - 273.15$
 $T = \theta + 273.15$

* The T scale is different because it does not depend on somewhat variable properties of substances such as the MP & BP of water.

2 fixed pts: 1. Absolute zero = 0 K

2. Triple point of water (temp at which ice, water & water vapour can co-exist) = 273.16 K = 0.01°C

The gap between the 2 fixed points is divided into 273.16 equal divisions. \therefore 1 div = 1 K

* It is defined in a slightly odd way so that the $^{\circ}$ K scale divs are equal in size to the Celsius scale divs.

\therefore A CHANGE in temp of 1 K = a CHANGE in temp of 1°C

THERMOMETERS

→ Any device which can be used to measure temp.

→ Uses a physical property of a material that changes with temp.

→ Most familiar: liquid-in-glass thermometer where the length of the column of liquid (mercury/alcohol) gets longer as the temperature increases because the liquid expands.

Hg (-40°C to 350°C)

Ethanol (-120°C to 80°C) used with red dye.

Adv: Over their temp range, their empirical centigrade scale is very close to the thermodynamic scale.

→ Other properties which can be used as the basis of thermometers are:

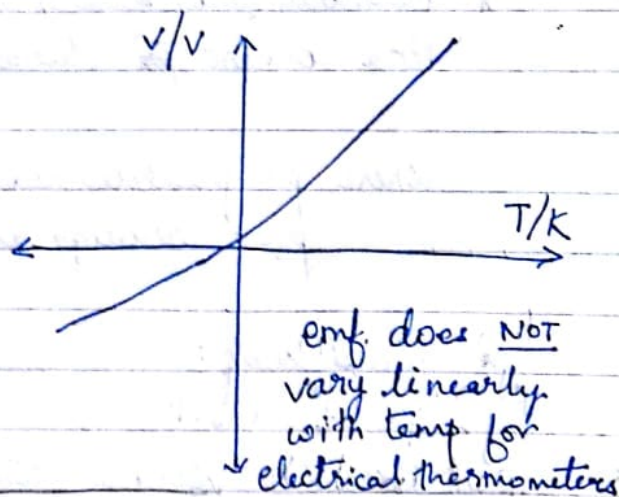
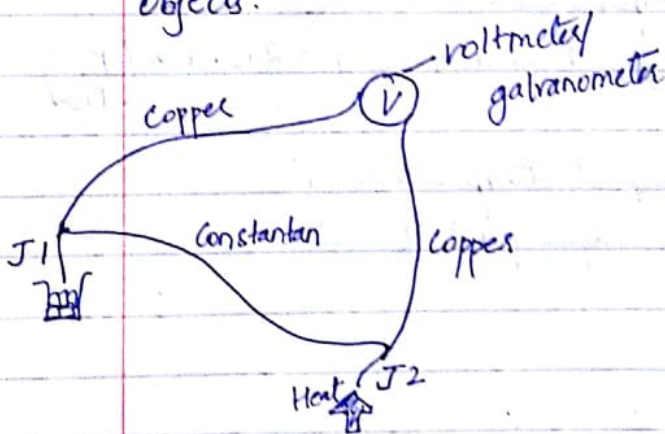
1. the resistance of an electrical resistor or thermistor
2. the voltage produced by a thermocouple [thermoelectric e.m.f.]
3. the colour of an electrically heated wire
4. the volume of a fixed mass of gas at constant pressure
5. the length of a column of liquid

⊗ → For metals, resistance \uparrow with temp at a fairly steady rate.

→ For thermistors (semiconductors used as resistance thermometers), the resistance changes rapidly over a relatively narrow range of temps. A small change in temp \Rightarrow A large change in resistance \therefore very sensitive.

- Range of metal resistance = -260°C to 1700°C \therefore wide range
- A common use of thermistor thermometers is as a temp sensor in car radiators.

- (*) → Thermocouple is another type of electrical thermometer & makes use of the thermoelectric effect.
- "When the junctions of 2 different conductors are at different temperatures, an e.m.f. (voltage) is developed."
- The relation between the e.m.f. and the temperature difference θ is not linear with thermodynamic state temp. & calibration is essential.
- The emf generated is rather small (for a thermocouple made of Cu & constantan wire, it is about 5 mV for $\Delta\theta$ of 100°C) but it is easy to arrange a circuit to amplify this emf & provide a direct reading which can then be calibrated.
- Can cover a large temp. range
- Since the sensing part (junction) is very small, it can be used to measure rapidly varying temps & the temps of small objects.



Feature	Resistance thermometer	Thermocouple thermometer
Robustness	very robust	robust
Range	resistance wire: wide thermistor: narrow	can be very wide
Size	large & \uparrow thermal capacity so slow response	small & \downarrow thermal capacity \therefore quick response & can measure temp at a point.

Resistance Thermometer

Thermocouple

Sensitivity thermistor: high 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.

* Empirical centigrade scale of temperature:

$$\theta = \frac{100 (P_{\theta} - P_i)}{(P_s - P_i)} \quad \text{based on property } P.$$

P_s , P_i and P_{θ} are the values of the property at the steam-point, ice-point and at temperature θ respectively.

* The Kelvin (K), unit of thermodynamic temperature, is the fraction $1/273.16$ of the thermodynamic temperature of the triple point of water.

* Thermodynamic scale of temperature:

For a constant ~~gas~~ volume gas thermometer, $T = 273.16 \times \left(\frac{P}{P_{tr}} \right)$

where p = pressure reading at temperature T
 p_{tr} = reading at triple point of water

* Celsius scale:

$$\theta = T - 273.15$$

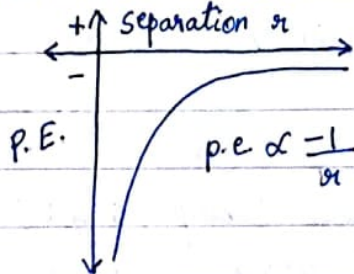
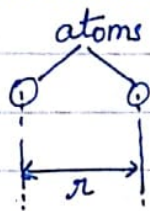
where θ = Celsius temperature ($^{\circ}\text{C}$)

T = Thermodynamic temperature (K)

Changes of state & kinetic model

- * In solids, the particles are close together, tightly bonded to their neighbours, and vibrating about their fixed, equilibrium positions.
- * In liquids, the particles are further apart but the bonds are still relatively strong and the molecules are free to move throughout the body of the liquid.
- * In a gas, the particles have broken free from their neighbours; they are widely separated and are free to move around within their container.
- * During melting & boiling, the temp. of a substance stops rising even though energy is still being supplied.
- * If the molecules move around more freely and faster, their K.E. has increased.

If they break free of their neighbours and become more disorder their electrical P.E. has increased.



Work must be done to separate neighbouring atoms.

- The e.p.e of 2 atoms very close together is large & negative.
- As separation \uparrow , e.p.e also \uparrow
- When the atoms are completely separated, their e.p.e is max. & has a value of zero

- * During the change of state:
 - there must be an input of energy
 - the temp. does not change
 - the molecules are breaking free of one another
 - their e.p.e is \uparrow

* In between the changes of state:

- input of energy raises the temp. of the substance
- molecules move faster
- K.E. is \uparrow

* Latent heat: the energy that must be supplied to cause a change of state of a substance without raising its temperature.

→ latent heat of fusion: solid to liquid

→ latent heat of vapourisation: liquid to gas.

* Temp. is a measure of the average K.E. of the molecules in a substance.

* The Internal Energy of a system is the sum of the random distribution of kinetic and potential ~~see~~ energies of its atoms or molecules.

• ~~Heat energy~~ / internal energy = sum of K.E. of atoms (ideal gas)

• Heat = energy transfer due to temp. difference

* Ways to change internal energy:

\uparrow • heating a gas

• doing work on a gas (compressing it)

• passing an electric current through a system

Basically, inputting some form of energy.

\downarrow • heat lost to surroundings

• gas expands \therefore doing work on the surroundings.

THE FIRST LAW OF THERMODYNAMICS

→ Related to principle of conservation of energy.

→ Thermodynamics is the study of processes involving the transfer of heat and the doing of work.

→ "The increase in internal energy of a system is equal to the sum of the heat added to the system and the work done on it."

$$\Delta U = Q + W$$

$\Delta U = \uparrow$ in internal energy

$Q =$ heat added (energy supplied by heating) ^{heat supplied to system}

$W =$ work done _{on system} (energy supplied by doing work)

+ve $Q =$ heat has been added to the system

-ve $Q =$ heat has been lost/removed from the system

+ve $W =$ work done on system

-ve $W =$ work done by system (can also be +ve \therefore notify)

* When no thermal energy is allowed to enter/leave a system, a change in pressure or volume of the system (e.g. gas in a cylinder fitted with piston - all insulated) in terms of thermodynamics is called an adiabatic change.

An adiabatic change can be achieved even if the cylinder & piston are not well insulated by moving the piston rapidly so that the heat has no time to flow in or out.

Heat can't escape $\Rightarrow \uparrow$ internal energy $\Rightarrow \uparrow$ temp.

In such cases, $Q = \underline{\text{zero}}$.

* On pure heating cases, $W = \underline{\text{zero}}$ and ΔU is always +ve as Q is +ve.

⊗ When a substance changes from solid to liquid, intermolecular bonds are broken, thus increasing the P.E. component of the internal energy. During the melting process, the temp. does not change, and \therefore the K.E. of the molecules does not change. Most substances expand on heating/melting, \therefore external work is done. By the first law, thermal energy must be supplied to the system & this thermal energy is the latent heat. Volume changes associated with evaporation are much greater than those associated with melting. The external work done is much greater during vapourisation, \therefore latent heat of vapourisation is much greater than latent heat of fusion.

V.IMP

Specific Heat Capacity [Specific means per unit mass]

The specific heat capacity of a substance is the ~~was~~ energy required per unit mass of the substance to raise the temp. by 1 K or 1°C.

E OR ΔQ

$$E = mc\Delta\theta$$

$$\Delta Q \propto \Delta\theta \quad \& \quad \Delta Q \propto m$$

$$\therefore \Delta Q \propto m\Delta\theta$$

$$\Rightarrow \Delta Q = mc\Delta\theta \quad c = \text{constant of proportionality}$$

where E = energy required

m = mass of material being heated

$\Delta\theta$ = temp. change we wish to achieve

c = specific heat capacity of substance.

$$\therefore c = \frac{E}{m\Delta\theta}$$

⊗ $c \propto 1/\text{gradient of temp/time graph.}$

Steeper the gradient \Rightarrow faster the substance heats up \Rightarrow lesser energy required \Rightarrow lower the specific heat capacity.

\rightarrow Determining 'c'

electrical

- Experiments to determine c often involve the use of ~~electric~~ heating.
 $E = W = Pt = QIt$ & then equated to $mc\Delta\theta$
- The use of such an equation neglects any heat loss; experiments should be designed to minimise this error.
- Supply a known ~~mass~~ amount of energy to a known mass of material and measure the rise in temp.
- An electrical heater is used as we can easily determine the amount of energy supplied.
- A thermometer/temperature sensor is used to monitor the block's temp as it is heated. The block must not be heated quickly; we want to be sure that the energy has time to spread throughout the material.
- The block should be insulated by wrapping it in a suitable material.
- It is better to determine c by recording values of temp. as it rises & plot a graph of θ against t .
Power supplied = $m \times c \times \text{gradient of graph.}$

→ Sources of error:

1. Rapid heating may cause different parts of block to be at different temps.
2. Thermal insulation is vital as if heat escapes, more energy will need to be supplied to the block for each degree rise in temp & experimental value of c will be too high.

One more solution: Cool the block below RT before beginning to heat it. Then, as its ^{temp} rises past RT, heat losses will be zero in principle as there is no temp diff. between block & surroundings.

Specific Latent Heat

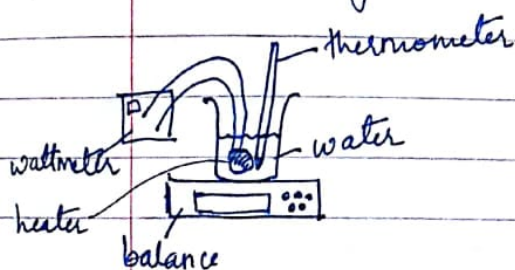
The specific latent heat of a substance is the energy required per kilogram of the substance to change its state without changing any change in temperature.

$$E = mL$$

$$L \text{ in } \text{J kg}^{-1} \text{ (no } ^\circ\text{C}^{-1} \text{ as no } \Delta\theta)$$

latent heat of fusion $<$ latent heat of vapourisation
as when a substance melts, fewer bonds are broken than when it boils.

→ Determining L



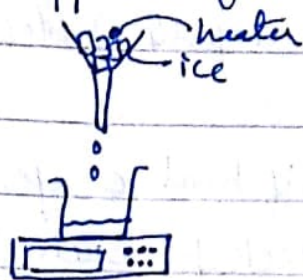
[wattmeter OR voltmeter + ammeter]

• water is heated at a steady rate & its mass recorded at equal intervals of time. $m \downarrow$ as it boils.

• a graph of mass against time should be a straight line whose gradient is the rate of mass lost. The wattmeter shows the rate at which energy is supplied to the water via the heater

$$L = \frac{\text{rate of supply of energy}}{\text{rate of loss of mass}}$$

- similar approach for L of fusion:



- Errors:

$L(v)$ - water is heated to produce steam which may escape causing heat loss (systematic error) $\therefore L \uparrow$.

$L(f)$ - ice is melted, energy from surroundings will conduct into the ice, so that measure of L will be an underestimate.