B1: THERMAL ENERGY TRANSFER

molecular theory in solids, liquids and gases
density ρ as given by $\rho = \frac{m}{V}$
Kelvin and Celsius scales are used to express temperature
the change in temperature of a system is the same when expressed with the Kelvin or Celsius scales
Kelvin temperature is a measure of the average kinetic energy of particles as given by $\overline{E}_k = \frac{3}{2} k_B T$
the internal energy of a system is the total intermolecular potential energy arising from the forces between the molecules plus the total random kinetic energy of the molecules arising from their random motion
temperature difference determines the direction of the resultant thermal energy transfer between bodies
a phase change represents a change in particle behavior arising from a change in energy at constant temperature
quantitative analysis of thermal energy transfers Q with the use of specific heat capacity c and specific latent heat of fusion and vaporization of substances L as given by $Q = mc\Delta T$ and $Q = mL$
conduction, convection and thermal radiation are the primary mechanisms for thermal energy transfer
conduction in terms of the difference in the kinetic energy of particles
quantitative analysis of rate of thermal energy transfer by conduction in terms of the type of material and cross-sectional area of the material and the temperature gradient as given by $\frac{\Delta Q}{\Delta t} = kA\frac{\Delta T}{\Delta x}$
qualitative description of thermal energy transferred by convection due to fluid density differences
quantitative analysis of energy transferred by radiation as a result of the emission of electromagnetic waves from the surface of a body, which, in the case of a black body, can be modeled by the Stefan–Boltzmann law as given by $L = \sigma A T^4$ where L is the luminosity, A is the surface area and T is the absolute temperature of the body
the concept of apparent brightness b
luminosity L of a body as given by $b = \frac{L}{4\pi d^2}$
the emission spectrum of a black body and the determination of the temperature of the body using Wien's displacement law as given by $\lambda_{max} T = 2.9 \times 10^{-3}$ m K where λ_{max} is the peak wavelength emitted.

(taken from Pearson textbook)

THERMAL CONCEPTS

THERMAL ENERGY

↳ Energy of particles that made up the matter.

HEAT

↳ Thermal energy that is observed, given up or transferred from one object to another

* In exam, use 'thermal energy' instead of heat

TEMPERATURE

- Degree of 'hotness' or 'coldness' of a body.

THERMAL EQUILIBRIUM

↳ Any 2 objects in thermal contact are in thermal equilibrium if there is no overall heat transfer between them

(no net heat movement)

THERMOMETER

↳ Intrument designed to measure temperature

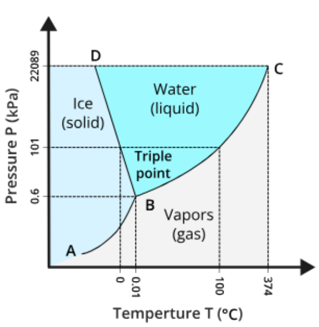
THERMODYNAMIC SCALE (ABSOLUTE ZERO)

↳ Usually when dealing with gas

↳ Lowest possible - 0 K

↳ Triple point of water is 273.16K

(a point where water coexist in 3 diff. phases)



↳ Measurement on the Kelvin scale aka the absolute temperature

↳ Normally used in microscopic scale

THERMOMETRIC PROPERTY

↳ Physical property which is measured to determine the temperature.

- Length for a liquid for glass tube thermometer
- Resistance for a resistance thermometer
- Pressure for a gas thermometer
- Voltage for a thermocouple thermometer

↳ Celcius scale (centrigade scale), in US - Farenheit

↳ Conversion:

- $T(°C) = \frac{5}{9}[T(°F) - 32]$
- $T(°F) = \frac{9}{5}T(°C) + 32$

↳ 2 fixed points in thermometer

- Ice point / melting point of ice
- Steam point / boiling point

Heat & Internal Energy

- Internal energy of a system is the total kinetic energy and potential energy of its particles / the total energy that the molecules possess (whenever we heat a substance, we increase its internal energy).
- Matter is made of tiny particles (eg: atoms/molecules) which are moving in random motion.
- The molecules have kinetics energy because they are moving.
- A molecule can have either:
  - Translational Kinetic Energy (the whole molecule is moving in a certain direction)
  - Rotational Kinetic Energy (the molecule is rotating about 1 or more axes)
  - Vibrational Kinetic Energy
- The molecules have potential energy because of the intermolecular forces.
- In ideal gas, intermolecular forces are negligible.
- From the microscopic point of view, temperature is a measure of average kinetic energy of the molecules in a substance.

  * If 2 substances have the same temperature, then their molecules have the same average kinetic energy.

Average kinetic energy: $\overline{E_k} = \frac{1}{2}m\overline{v^2} = \frac{3}{2}kT$

$\frac{3}{2}$: we only have one type of motion (probably translational)

k = Boltzman constant

T = temperature

$$\therefore \bar{V}^2 \propto T$$

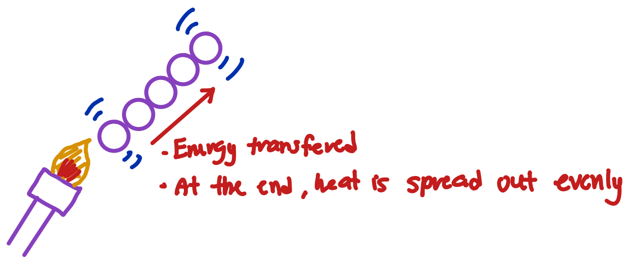
($\bar{v}$ is average speed)

Thermal Energy Transfer

1. Conduction

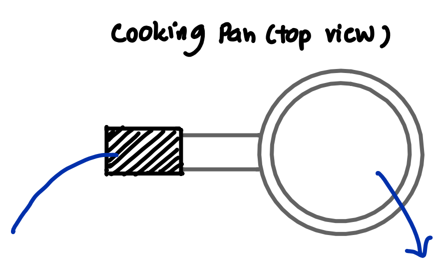
↳ Happen in Solids, particles are close together, lots of collisions occur

↳ Vibrating particles transfer energy to neighbouring particles.



↳ Thermal Conductivity is a measure of how good a thermal conductor is at transferring energy through itself when in steady state.

↳ Steady state : When the temperature distribution remains constant, even though heat is continously flowing through the material.



plastic / rubber

↳ low thermal conductivity

↳ A great insulator

Steel / metal

↳ High thermal conductivity because contains freely moving electrons helping to pass on the energy.

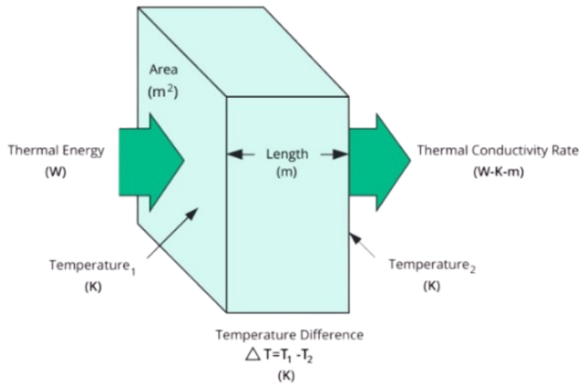
$$\text{thermal conductivity} = \frac{\text{rate of energy transfer}}{\text{area of material} \times \text{temp. gradient across conductor}}$$

rate of energy transfer = thermal conductivity × area of material × temp. gradient across conductor

$$\frac{\Delta Q}{\Delta t} = -k \times A \times \frac{\Delta T}{\Delta x}$$

Where: - An energy ΔQ is transferred across the material of a time in Δt through an area, A

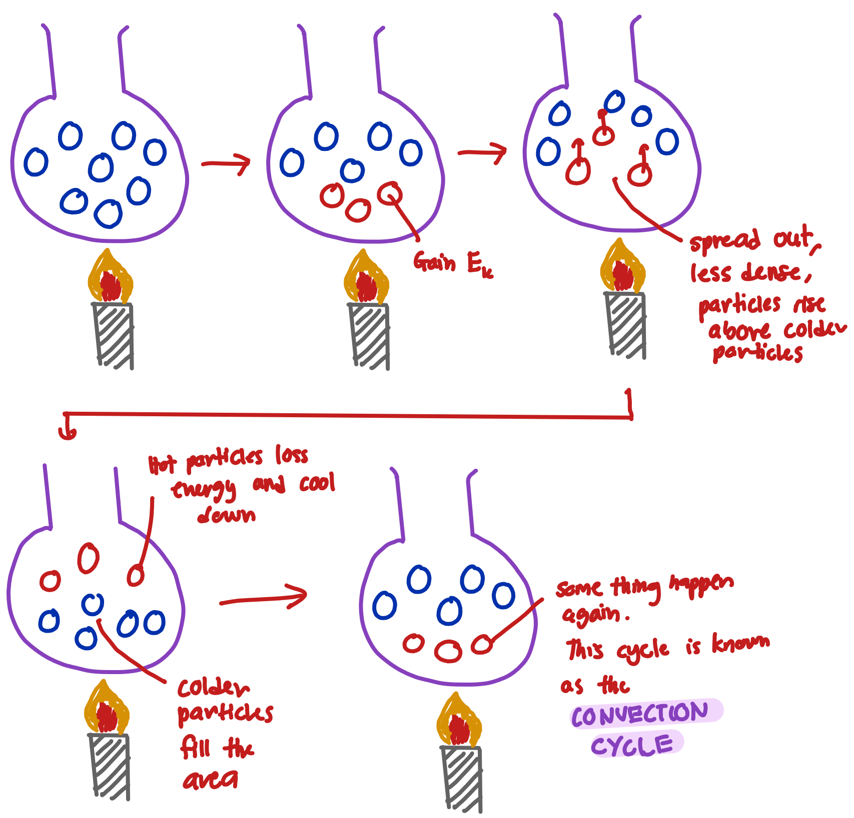
- When there is a temperature difference, $\Delta T = T_1 - T_2$ across the conductor that has a length, Δx



Energy flow through a conductor of area A and length Δx

2. Convection

↳ Occurs in fluids (gas or liquid)



3. Radiation

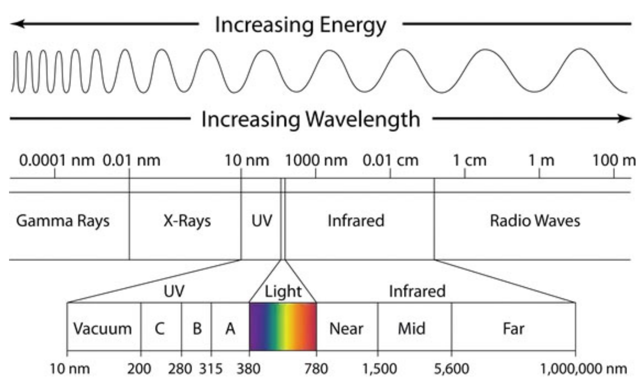
↳ is the transfer of energy by means of electromagnetic radiation. This radiation travels as a wave but does not need a medium in which to move (propagate)

↳ For example : Energy received from the Sun.

↳ Hotter objects = More radiation

Black Body Radiation

- A black body is one that absorbs and emits almost 100% (perfect) wavelengths of electromagnetic radiation that fall on it.
- Black body is an idealization.
- Closest to black body : Sun, Stars, Charcoal (because surface is black, dull and rough) - difficult to release energy
- The radiation appears coloured, depending on the temperature on the enclosure.
- Black body ≠ Black body radiation



(Electromagnetic Spectrum)

↳ At low temperature (low Energy), radiation is in IR region, as temperature increase the colour emitted first is red. Became white when temperature is high enough.

↳ Power radiated by black body obeys Stefan-Boltzmon Law (aka. Luminosity Law)

"The amount of energy per second (power) radiated by a body depends on its surface area, A, absolute temperature, T, and the property of the surface.

$$P = e\sigma AT^4$$

* $A = 4\pi r^2$

e = emmisivity of the surface (range 0 - 1) | $e = 0$ - not a black body at all. $e = 1$ - the perfect black body.

σ = stefan-Boltzmon constant ($5.67 \times 10^{-8}\ Wm^{-2}K^{-4}$)

↳ However, power received by Earth from Sun is actually much lower than its actual value.

↳ A body of emmisivity e that is kept at some temperature, T_1:

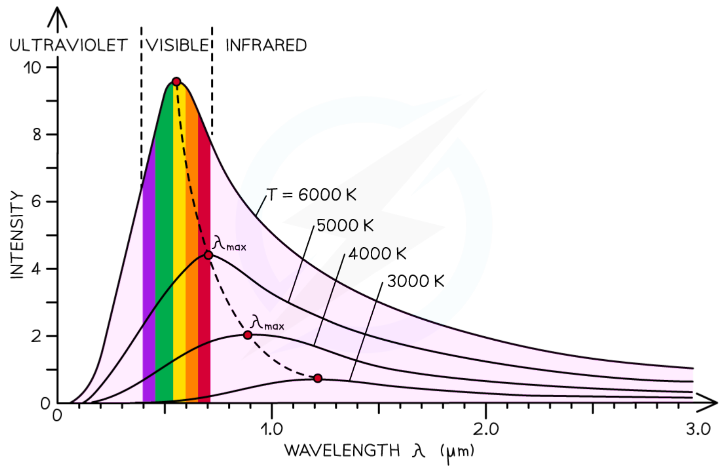
- will radiate power at a rate of, $P_{out} = e\sigma AT_1^4$
- will absorb power at a rate of, $P_{in} = e\sigma AT_2^4$

↳ The net Power lost by the body is:

$$P_{net} = P_{in} - P_{out} = e\sigma A(T_2^4 - T_1^4)$$

At thermal equilibrium, $P_{net} = 0$, $T_1 = T_2$ (Body's temp = surrounding's temp)

↳ Black body spectra for a body at different temperature shown below.



As Temperature increases:

↳ Intensity of λ ↑, shorter λ ↑↑

↳ Total E emitted ↑ because Power radiated ↑

↳ Curve skewed to the left

↳ Curve move more into the red region

↳ max λ are all in IR region

↳ Peak λ moves to the left

↳ curve get closer to x-axis but never touch it.

* Must know how to draw!

Observational Astronomy and Black Body Radiation

- Most stars are black body radiators to a very close approximation.
- Stefan-Boltzman and Wein's Law is crucial in astronomy
- Luminousity of stars allow comparisons between stars of similar age and size.
- Logically, the brighter the star, the closer it is to us

Apparent Brightness, b

- Called 'apparent' because it only describes how bright the body appears to us, not its actual brightness
- Unit is Wm^{-2}

$$b = \frac{L}{4\pi d^2}$$

L = Luminosity

d = distance

- symbol for luminosity of the Sun: $L_\odot$
- 〃 〃 radius of the sun: $R_\odot$

Thermal Properties of Matter

1. Heat capacity / thermal capacity

↳ The energy required to raise its temperature by 1 K

$$C = \frac{\text{heat input}}{\text{temperature used}}$$

$$= \frac{\Delta Q}{\Delta T} \quad (\text{unit} : JK^{-1})$$

→ where : ΔQ : the change in thermal energy in J

ΔT : the change in temperature in K (In calculation, can use °C)

2. Spesific heat capacity

↳ The energy required to raise the temperature of 1kg of a substance by 1 K

$$c = \frac{\Delta Q}{m\Delta T} \quad (\text{unit} : J\,kg^{-1}\,K^{-1})$$

→ where : ΔQ : the change in thermal energy in J

ΔT : the change in temperature in K (In calculation, can use °C)

m : mass of the materials in kg

NOTE : ΔT is always +ve because heat transfer from

HIGH temperature region ⟶ LOW temperature region

↳ Assumptions in the Kinetic Theory:

1) Matter is made of tiny randomly moving particles.
2) Particles are spherical in shape
3) Volume of particles is considered negligible to the volume of container
4) Particles experience elastic collisions (E_k and momentum are conserved)
5) Particles are in constant speed (because momentum conserved)
6) Pressure of the system came from collision of molecules with the wall of the container.
7) The impact time of collision < time it took for particles to collide

↳ When a substance changes phase, the temperature remains constant even though thermal energy is still being transferred (because energy supplied to the system is used to overcome the intermolecular forces)

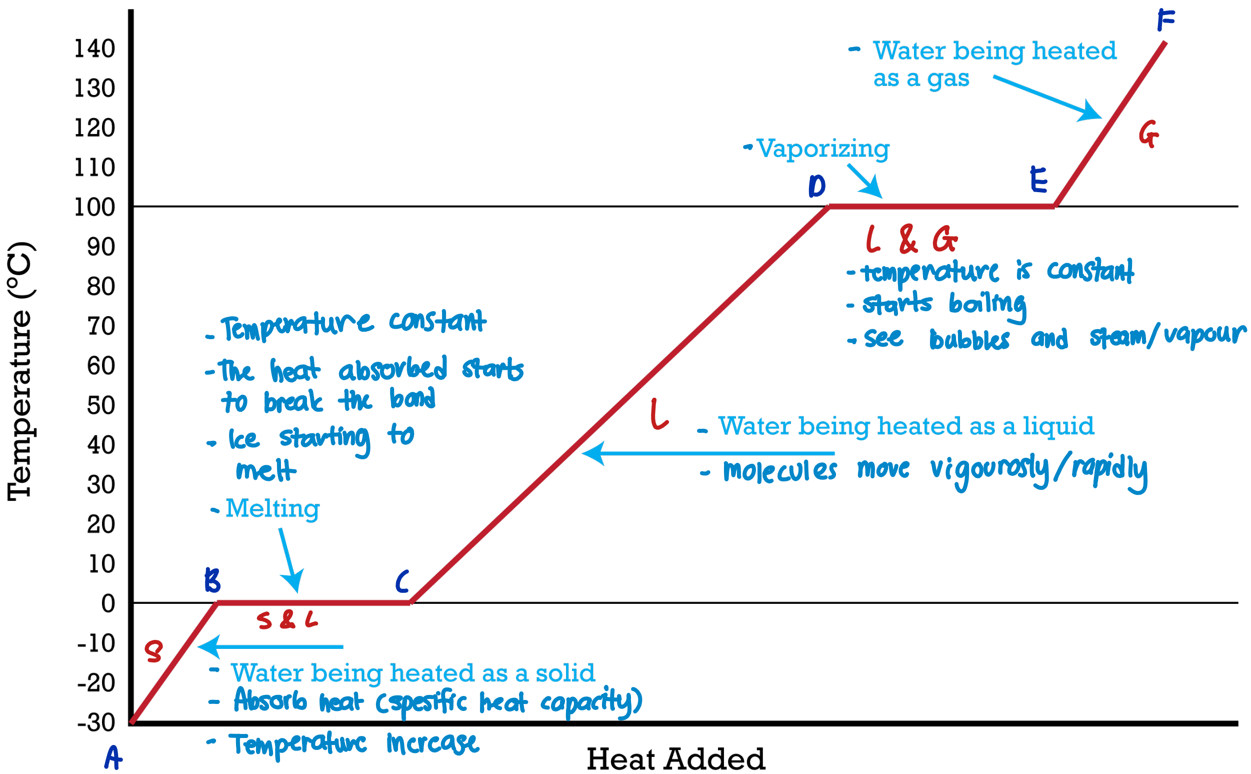
↳ The amount of energy associated with the phase change is called the latent heat.

↳ Term of latent heat for:

- Solid and liquid - fusion
- liquid and gas - evaporation

↳ In idealized situation (no energy loss), energy transfer in a solid substance is at a constant rate

Heating Curve for Water at 1.00 atm Pressure



- Difference in gradient

  Why $\overrightarrow{AB}$ gradient > $\overrightarrow{CD}$ gradient ?

  ↳ Ice's SHC is $\frac{1}{2}$ of water

  ↳ Work done to break the bond of solid/ice < water

  ↳ This is because of arrangement (ice = very packed, so need higher energy)

3. Spesific latent heat, L

↳ The amount of energy per unit mass absorbed or released during a change of phase

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

Where : Q : Heat required or given off during the phase change in J

m : mass of the materials in kg

(a) Spesific latent heat of vaporization, L_v

↳ The thermal energy which must be supplied per unit mass to change a liquid into gas (and vise versa) without change in temperature

$$Q = mL_v$$

* Example : L_v of water is $2.3 \times 10^6 \ \mathrm{J\,kg^{-1}}$

(b) Spesific latent heat of fusion, L_f

↳ The thermal energy which must be supplied per unit mass to change a solid into liquid (and vise versa) without change in temperature

$$Q = mL_f$$

* Example : L_f of water is $3.3 \times 10^5 \ \mathrm{J\,kg^{-1}}$

Evaporation Process

↳ Liquid (like water) ⟶ gas below its boiling point.

↳ Evaporation takes place at the surface of liquids.

↳ If a liquid is below its boiling point, on average, the molecules do not have sufficient energy to leave the surface

↳ Molecules with high enough velocity will escape from the liquid entirely and become part of the gas phase

* Only those molecules that have kinetic energy above a particular value can escape to the gas phase.

* This means that it is the slower moving ones that are left behind. In other words, the temperature of liquid falls as a result of evaporation.

↳ Factors that affect evaporation rate

1) Total Surface Area - ↑ TSA of liquid ↑ rate of evaporation
2) Temperature above surface area of liquid - ↑ Temperature ↑ rate of evaporation
3) Air movement above the surface of liquid - ↑ Air movement ↑ rate of evaporation
4) Humidity of air above the surface of liquid - ↑ Humidity ↑ rate of evaporation