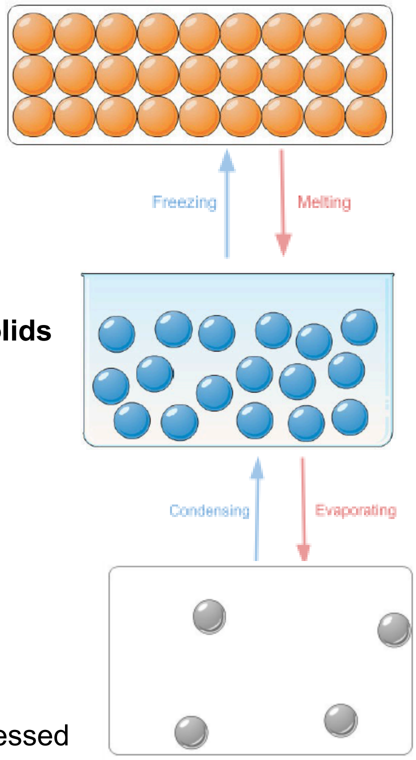
CAIE Physics IGCSE

Topic 2: Thermal Physics

Summary Notes

2.1 Kinetic particle model of matter

2.1.1 States of matter



- Solids
  - Molecules close together in regular pattern
  - **Strong intermolecular forces of attraction**
  - Molecules vibrate but can’t move about
  - Cannot flow, have fixed shape and cannot be compressed
- Liquids
  - Molecules close together in random arrangement
  - **Weaker intermolecular forces of attraction than solids**
  - Molecules move around each other
  - Flow, take the shape of their container and cannot be compressed
- Gases
  - Molecules far apart in random arrangement
  - **Negligible/very weak intermolecular forces**
  - Molecules move quickly in all directions
  - Flow, completely fill their container and can be compressed

2.1.2 Particle Model

Brownian motion:
- Gas molecules move rapidly and randomly
- This is due to collisions with other gas molecules
- **Massive particles may be moved by light, fast-moving molecules**

The temperature of a gas is related to the average kinetic energy of the molecules. The higher the temperature, the greater the average kinetic energy and so the faster the average speed of the molecules. When the kinetic energy of the molecules is zero, the temperature of the substance is known as “absolute zero”, the lowest possible temperature (-273ºC).

2.1.3 Gases and the absolute scale of temperature

The unit Kelvin is often used in this situation. 1 Kelvin has the same magnitude as 1ºC, but Kelvin is shifted such that absolute zero (-273ºC) is equal to 0 Kelvin. To convert between Kelvin and degrees Celsius:

$$T(\text{in K}) = T(\text{in }^{\circ}\text{C}) + 273$$

Gases exert pressure on a container due to collisions between gas molecules and the wall. **When the molecules rebound off the walls, they change direction so their velocity and therefore momentum changes. This means they exert a force because force is equal to the change in momentum over time.**

- At a constant volume, if the temperature increases, the pressure increases because the molecules move faster so they collide harder and more frequently with the walls.
- At a constant temperature, if the volume increases, the pressure decreases because the molecules collide less frequently with the walls.
    - **For a gas at fixed mass and temperature, $pV = constant$, where p is the pressure in Pascals and V is the volume in m^3.**

2.2 Thermal properties and temperature

2.2.1 Thermal expansion of solids, liquids and gases

When something is heated, it expands because the molecules take up more space:

- **When a solid is heated, the molecules vibrate more but stay in place, so the relative order of magnitude of the expansion is small.**
- **When a liquid is heated, it expands for the same reason as a solid, but the intermolecular forces are less so it expands more.**
- **When a gas is heated, the molecules move faster (increase in the average kinetic energy of the molecules) and further apart, so the relative order of magnitude of the expansion is the greatest.**

Some applications and consequences of thermal expansion include:

- Railway tracks having small gaps so that they don't buckle when they expand
- The liquid in a thermometer expands with temperature and rises up the glass

2.2.2 Specific heat capacity

When the temperature of a body rises, its internal energy increases and its molecules vibrate.

- **The specific heat capacity is the amount of energy required to raise the temperature of 1kg of a substance by 1℃.**
    - $change\ in\ thermal\ energy = mass \times specific\ heat\ capacity \times temperature\ change$ $\Delta E = mc\Delta T$ **where ΔE is the change in thermal energy in J, c is specific heat capacity in $Jkg^{-1}℃^{-1}$, m is mass in kg and ΔT is change in temperature in ℃.**
    - The specific heat capacity of a material can be found by insulating the material and placing a thermometer and an immersion heater inside. The total **work done** by the heater (found by the **power** (**current** times **potential difference**) times **time**) can be divided by the **mass** of the material and the **change in temperature** to find the **specific heat capacity**.
- The thermal capacity of a body is how much energy needs to be put in to raise its temperature by a given amount.
    - **The thermal capacity of a system is given by:** $thermal\ capacity = mc$

2.2.3 Melting, boiling and evaporation

Melting and boiling occur when energy is put in to a body without a change in temperature.

- The melting point is the temperature at which a given solid will melt when heated.
- The boiling point is the temperature at which a given liquid will turn into a gas when heated.
- Condensation is when some molecules in a gas do not have enough energy to remain as separate molecules, so they come close together and form bonds, becoming liquid.
- Freezing is when the molecules in a liquid slow down enough that their attractions cause them to arrange themselves into fixed positions, becoming solid.

The melting point of water at atmospheric pressure is: 0ºC

The boiling temperature of water at atmospheric pressure is: 100ºC

Condensation occurs when gas particles lose energy and move closer together, transitioning into a liquid state as intermolecular forces pull them into a more ordered arrangement. **Solidification** happens when liquid particles lose further energy, slowing down and locking into a fixed, rigid structure, forming a solid with particles vibrating in place.

- Evaporation is the escape of molecules with higher energy from the surfaces of liquids.
- After they escape, the remaining molecules have a lower average kinetic energy which means the temperature is lower (i.e. evaporation cools the liquid).
- **To increase the rate of evaporation:**
    - **Increase temperature: more higher energy molecules**
    - **Increase surface area: more molecules at the surface**
    - **Draught: molecules are removed before returning to the liquid**

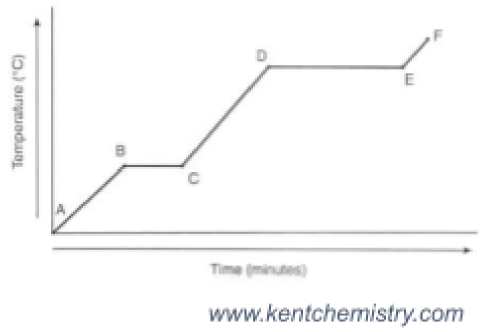
Evaporation is different to boiling because it can happen at any temperature and only occurs at the surface of the liquid.

- **The specific latent heat is the amount of energy needed to change the state of 1kg of a substance.**
    - **Specific latent heat of fusion is the energy to melt/freeze**
    - **Specific latent heat of vaporization is energy to boil/condense**
- $energy = mass \times specific\ latent\ heat \qquad E = ml$
    - **where E is the energy needed in J, m is the mass in kg, and l is the specific latent heat in Jkg^{-1}.**

When a body changes state, energy goes towards making the molecules more free from each other rather than increasing their kinetic energy.

Graph showing the temperature of ice with time when energy is put in at a constant rate:

- From A to B the ice is rising in temperature
- From B to C it is melting into water
- From C to D the water is rising in temperature
- From D to E the water is boiling into steam
- From E to F the steam is rising in temperature



2.3 Transfer of Thermal Energy

2.3.1 Conduction

Experiments to Demonstrate Good and Bad Thermal Conductors:

- Use a metal rod with wax at equal distances along it. Heat one end of the rod:
  - **Good conductor (e.g., metal)**: Wax melts quickly further along the rod.
  - **Bad conductor (e.g., wood, plastic)**: Wax remains intact, showing poor heat transfer.
- Compare temperature changes using a thermometer or thermal sensors on materials like copper (good) vs. wood (bad).

Thermal Conduction in Solids:

- **Lattice vibrations**: In non-metals, heat energy causes atoms in the lattice to vibrate and transfer energy to neighboring atoms.
- **Free electrons**: In metals, free (delocalised) electrons rapidly transfer heat as they move through the lattice, making metals excellent conductors.

Why Conduction Is Poor in Gases and Liquids:

- **Gases**: Particles are far apart, so collisions are infrequent, leading to inefficient energy transfer.
- **Liquids**: Particles are closer than in gases but lack the rigid structure for effective energy transfer like in solids.
- Some solids (e.g., ceramics, glass) conduct heat better than insulators like wood or plastic but are less efficient than metals due to the absence of free electrons.

2.3.2 Convection

- Convection is a key method of thermal energy transfer in liquids and gases.
- **Mechanism**: Heat causes the fluid to expand, reducing its density. The warmer, less dense fluid rises while cooler, denser fluid sinks, creating a convection current.
- **Experiments to Illustrate Convection**:
  - Use a beaker of water with dye or potassium permanganate crystals at the bottom. Heat the base of the beaker to observe the upward movement of warm water.
  - Smoke box: A box with a candle under one chimney shows smoke entering through the other chimney, visualizing convection currents.

2.3.3 Radiation

Thermal radiation is infrared radiation emitted by all objects due to their temperature.

Medium independence means thermal radiation does not require a medium and can transfer energy through a vacuum.

Effect of Surface Color and Texture:

- **Black/Dull surfaces**: Good absorbers and emitters of radiation.
- **White/Shiny surfaces**: Poor absorbers and emitters; good reflectors of radiation.

For an object to maintain constant temperature, energy transfer away must equal energy received.

If energy received > energy lost: Object heats up.

If energy received < energy lost: Object cools down.

The earth's temperature balance is influenced by the balance between incoming **solar radiation** and emitted **infrared radiation**, as well as factors like greenhouse gases and surface reflectivity.

Experiments: Good and Bad Emitters:

- Place two containers (one black, one shiny) of hot water in a cool room. Measure cooling rates; black emits more heat.

Experiments: Good and Bad Absorbers:

- Place black and shiny surfaces under a heat lamp. Measure temperature rise; black absorbs more radiation.

Rate of Radiation Emission:

- Depends on:
  - **Surface temperature**: Hotter surfaces emit more radiation.
  - **Surface area**: Larger areas emit more radiation.

2.3.4 Consequences of Thermal Energy Transfer

Basic Applications and Consequences:

- **Heating Objects (e.g., Kitchen Pans)**:
  - **Conduction**: Heat travels through the metal pan from the base to the food due to the high thermal conductivity of metals.
  - Handles are often made of insulators (e.g., plastic) to prevent burns.
- **Heating a Room by Convection**:
  - Warm air from heaters rises as it becomes less dense, displacing cooler air which sinks, creating a convection current to evenly distribute heat in the room.

Complex Applications and Consequences:

- **A Fire Burning Wood or Coal**:
  - **Conduction**: Heat transfers through the solid fuel, allowing it to ignite further.
  - **Convection**: Hot air rises, creating upward currents that carry smoke and warm the surrounding area.
  - **Radiation**: Infrared heat radiates directly from the flames to warm nearby objects.
- **A Radiator in a Car**:
  - **Conduction**: Heat from the engine coolant transfers to the radiator metal.
  - **Convection**: Air passes over the radiator, carrying heat away as the heated air rises.
  - **Radiation**: Some heat is lost directly as infrared radiation to the surroundings.