19 Thermal Physics

19.1 Internal Energy and Temperature

Energy transfer between objects takes place if

- One object **exerts a force** and **do work** on another object.
- There is a **temperature difference** between two objects.
- The **internal energy** of an object is the energy of its molecules due to their individual movements and positions.
- **Thermal energy** is the internal energy of an object **due to its temperature**.

The internal energy of an object is increased by

- **Heating** the object.
- **Work done** on the object.

If the internal energy stays constant, the energy transfer by heating and work done must balance each other out.

The **first law of thermodynamics** states the **change of internal energy** of the object is equal to the **total energy transfer** due to work done and heating.

States of Matter

- **Solid**: molecules vibrate randomly about **fixed positions**.
  - The higher the temperature, the more the molecules vibrate.
  - The solid **melts** if its molecules vibrate so much they **break free from each other**.
- **Liquid**: molecules move about at random **in contact with each other**.
  - The higher the temperature, the faster its molecules move.
  - The liquid **vaporise** if its molecules have **sufficient kinetic energy** to break free.
- **Gas**: molecules move about at random but **much further apart** on average than in a liquid.
  - The molecules speed up when heated up.

The **internal energy** of an object is the sum of the random distribution of the kinetic and potential energies of its molecules.

Temperature

Objects in **thermal equilibrium** are at the same temperature, and **no overall heat transfer** by heating take place.

A **temperature scale** is defined in terms of **fixed points** which are standard degrees of hotness.

- **Celsius scale**:
  - **Ice point** 0°C is the temperature of pure melting ice.
  - **Steam point** 100°C is the temperature of steam.
- **Absolute scale** (Kelvin):
  - **Absolute zero** 0°C is the **lowest possible temperature** - the object has **minimum internal energy**.
  - **Triple point** of water: temperature which ice, water and water vapour co-exist in thermodynamic equilibrium.

temperature in C° = absolute temperature in kelvins $- 273.15$

19.2 Specific Heat Capacity

The **specific heat capacity** c of a substance is the energy needed to raise the temperature of unit mass of the substance by 1K without change of state.

The unit of c is $\mathrm{J\,kg^{-1}K^{-1}}$.

The energy needed to raise the temperature of mass m of a substance by ΔT is

$$\Delta Q = mc\Delta T$$

Specific Heat Capacity Measurement

- A block of metal of mass m in an **insulated container**.
- An **electrical heater** inserted in the metal.
- A **thermometer** inserted into the metal to measure temperature rise ΔT.

Assuming no heat loss to the surroundings

$$mc\Delta T = IV\Delta t$$
$$c = \frac{IV\Delta t}{m\Delta T}$$

The specific heat capacity of a liquid can be measured using liquid in an **insulated calorimeter**.

$$IV\Delta t = m_L c_L \Delta T + m_{\mathrm{cal}} c_{\mathrm{cal}} \Delta T$$

Continuous Flow Heating

Assuming no heat loss to the surroundings, for a mass m of liquid passing through the heater in time Δt.

$$IV = mc\frac{\Delta T}{\Delta t}$$

where ΔT is the temperature rise of the water.

19.3 Change of State

- **Gas** has a much **lower density** than that of the same substance in liquid or solid state.
  - Solids and liquids have molecules packed **in contact** with each other.
  - Molecules of a gas are on average **separated by large distances**.
- **Solids** cannot flow.
  - Molecules in a solid are **locked together by strong force bonds**.
  - Molecules in solids and gas have **too much kinetic energy** for the force bonds to keep molecules fixed to each other.

Latent Heat

- A solid **heated at its melting point**, its atoms vibrate so much they **break free from each other**.

  The energy needed to melt a solid at its melting point is called the **latent heat of fusion** - latent heat is **released** when a liquid solidifies.
- A liquid **heated at its boiling point**, its molecules **gain enough kinetic energy** to overcome the bonds that hold them close together.

  The energy needed to vaporise a liquid is called **latent heat of vaporisation**.

No temperature change takes place during melting and boiling, even though the solid is being heated.

Sublimation is when solid vaporise directly when heated.

- **Specific latent heat of fusion** l_f of a substance is the energy needed to change the state of unit mass of the substance from solid to liquid without change of temperature.
- **Specific latent heat of vaporisation** of a substance is the energy needed to change the state of unit mass of the substance from liquid to vapour without changing temperature.

$$Q = ml$$

The unit of specific latent heat is $\mathrm{J\,kg^{-1}}$