19 Thermal Physics

19.1 Internal Energy and Temperature

Energy transfer between two objects takes place if

- One object **does work** on another object by **exerting a force**.
- One object is hotter than the other project, so **energy is transferred by heating** because of a **temperature difference** between the two objects.

Internal Energy

- The **internal energy** of an object is the energy of its molecules due to their individual movements and positions.
- The internal energy of an object due to its temperature is called **thermal energy**.

The internal energy of an object is increased by

- Energy transfer **heating** the object.
- **Work done** on the object, e.g. electricity.

If internal energy of an object **stays constant**, then either

- There is **no energy transfer** by heating and no work is done.
- Energy transfer by heating and work done **balance each other out**.

The **first law of thermodynamics** states

$$\text{Change of internal energy of the object} = \text{total energy transfer due to work done and heating}$$

The **direction of energy transfers** determines whether the overall internal energy of the object increased or decreases.

States of Matter

A **molecule** is the smallest particle of a pure substance that is **characteristic of the substance**.

An **atom** is the smallest particle of an element that is characteristic of the element.

- In a **solid**, the molecules are **held to each other** by forces due to the electrical charges of the protons and electrons in the atoms.
  - Molecules **vibrate randomly** about fixed positions.
  - The higher the temperature of the solid, the more the molecules vibrate.
  - The energy supplied to raise the temperature of a solid **increases the kinetic energy of the molecules**.
  - If the temperature is raised enough, the solid **melts -** the molecules vibrate so much that they **break free from each other** and the substance loses its shape.

- The energy supplied to melt a solid **raises the potential energy** of the molecules because they break free from each other.

- In a **liquid**, the molecules move about at random **in contact with each other**.
  - The forces between the molecules are not strong enough to hold the molecules in fixed positions.
  - The higher the temperature of a liquid, the faster its molecules move.
  - The energy supplied to a liquid to raise its temperature **increases the kinetic energy of the liquid molecules**.
  - Heating the liquid further causes it to **vaporise** - the molecules have **sufficient kinetic energy** to break free and move away from each other.
- In a **gas**, the molecules move about at random but **much further apart** on average than in a liquid.
  - Heating a gas makes the molecules speed up and so **gain kinetic energy**.

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

Increasing the internal energy of a substance increases the kinetic/potential energy associated with the random motion and positions of its molecules.

The Temperature Scale

- The temperature of an object is a measure of the **degree of hotness** of the object. The hotter an object the more **internal energy** it has.
- For any two objects at the same temperature, they are in **thermal equilibrium**, and **no overall energy transfer by heating** will take place.

A temperature scale is defined in terms of **fixed points** - standard degrees of hotness that can be accurately reproduced.

The **Celsius scale** of temperature in units C° is defined in terms of

- **Ice point** 0C° - the temperature of pure melting ice.
- **Steam point** 100C° - the temperature of steam at standard atmospheric pressure.

The **absolute scale** of temperature in units kelvins is defined in terms of

- **Absolute zero** 0K - the lowest possible temperature.
- **Triple point of water** - 273.1K, the temperature which ice, water and water vapour co-exist in thermodynamic equilibrium.

$$\text{Temperature in Celsius} = \text{absolute temperature in kelvins} - 273.1$$

The **absolute zero** is the lowest possible temperature, because an object at absolute zero has **minimum internal energy**, regardless of the substance the object consists of.

19.2 Specific Heat Capacity

The temperature rise of an object when heated depends on

- **Mass** of the object.
- **Amount of energy** applied to it.
- **Substance** from which the object is made.

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 is

$$\text{Energy needed } \Delta Q = mc\Delta t$$

Specific Heat Capacity Measurements (Solid)

1. A block of metal of **known mass** m in an **insulated container** is used.
2. An **electrical heater** is inserted into a hole drilled in the metal to supply a **measured amount of electrical energy**.
3. A **thermometer** is inserted into a hole drilled in the metal to measure the **temperature rise**.
4. A **small amount of water or oil** in the thermometer hole will **improve the thermal contact** between the thermometer and the metal.

Assuming **no heat loss** to the surroundings.

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

Specific Heat Capacity Measurements (Liquid)

1. A **known mass** of liquid is used in an **insulated calorimeter** of know mass and known specific heat capacity.
2. An **electric heater** is placed in the liquid to heat it directly.
3. A **thermometer** is inserted into the liquid to measure the **temperature rise**.

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

So c can be calculated because all other quantities are known.

Continuous Flow Heating

For mass m of liquid passing through the heater in a time Δt at a steady flow rate.

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

19.3 Change of State

- The **density of a gas** is much less than the density of the same substance in liquid or solid state.

  Molecules of liquid and solid are **packed together in contact** with each other. Whereas the molecules of gas are on average **separated from each other** by relatively large distances.

- Liquid and gases **can flow** but solids can't.

  The atoms in a solid are **locked together** by strong force bonds, which atoms are unable to break free from.

  In a liquid or gas, the molecules are not locked together because they have **too much kinetic energy**, and the force bonds are **not strong enough** to keep the molecules fixed to each other.

Latent Heat

- When a **solid is heated at its melting point**, its atoms vibrate so much that they break free from each other. The solid therefore **becomes a liquid** due to the energy supplied at the melting point.

  The energy needed to melt a solid at its melting point is called **latent heat of fusion**.

  During melting, **no temperature change** takes place even though the solid is being heated.

- Latent heat is released when a **liquid solidifies**.

  The liquid molecules **slow down as the liquid cools** until the temperature decreases to the melting point, where the molecules move slowly enough for the force bonds to **lock the molecules together**.

  Some latent heat is released **keeps the temperature at the melting point** until all liquid has solidified.

- When a **liquid is heated at its boiling point**, the molecules gain kinetic energy to **overcome the bonds** that hold them close together. The molecules therefore **break away from each other** to form bubbles of vapour in the liquid.

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

- Latent heat is released when a **vapour condenses**.

  Vapour molecules slow down as the vapour is cooled. The molecules move slowly enough for the force bonds to **pull the molecules together** to form a liquid.

Some solids **vaporise directly** when heated in a process called **sublimation**.

In general, much more energy is needed to vaporise a substance than to melt it.

- The **specific latent heat of fusion** of a substance is the energy needed to **change the state of unit mass of the substance** from solid to liquid without change in temperature.

- The **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 gas without change in temperature.

$$\text{Energy needed } Q = ml$$

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