Unit 5

Heat Conduction and Calorimetry

Introduction to Heat Transfer

Energy is constantly being transferred in different forms around us, and one important form of energy transfer is heat. Heat energy is vital for many aspects of daily life, from cooking to the functioning of advanced technologies like refrigerators and jet engines. It plays a key role in making internal energy usable.

It's common to confuse heat with temperature, but they are different concepts. This unit will help you understand the differences and relationships between them. You'll also learn about thermal expansion, heat transfer due to temperature changes, phase changes, internal energy, and work done by a system.

Understanding Heat

What is Heat? When you leave a hot cup of tea in a room, it cools down over time. This cooling happens because energy is transferring from the tea (which is hotter) to the surrounding air (which is cooler). This energy transfer, moving from a hotter object to a cooler one, is called **heat**.

Heat is a form of energy, measured in joules (J). When the temperature of the tea and the surrounding air equalizes, thermal equilibrium is reached, and no net heat transfer occurs.

Heat vs. Internal Energy and Work A key point is that an object never "contains" heat; rather, heat refers to the energy transfer between systems. When an object is heated, its temperature rises because the average kinetic energy of its particles increases, leading to an increase in **internal energy**—the total energy stored in the object.

Heat and work are two ways to transfer energy. For instance, when heat is supplied to a gas in a cylinder with a movable piston, some of the energy increases the internal energy (temperature), and some of it does work by moving the piston. This illustrates the relationship between heat, internal energy, and work.

Heat Transfer Mechanisms

Heat can be transferred in three main ways:

1. **Conduction:** Heat transfers through direct contact between materials. For example, when you hold a metal rod with one end in a flame, the heat travels through the metal to your hand. Metals are good conductors of heat, while materials like wood are insulators, slowing down heat transfer.
2. **Convection:** In fluids (like air or water), heat transfers through the movement of the fluid itself. When a fluid is heated, the warmer, less dense part rises while the cooler, denser part sinks, creating a cycle that transfers heat.
3. **Radiation:** Heat can also transfer through electromagnetic waves, like the warmth you feel from the sun or a fire, even without direct contact.

Heat Capacity and Specific Heat

Heat Capacity is the amount of heat needed to change the temperature of an object by 1°C or 1K. It depends on the mass and the properties of the substance.

Specific Heat Capacity refers to the amount of heat required to change the temperature of 1 kg of a substance by 1°C. Different materials have different specific heat capacities, with water having a notably high specific heat capacity, making it effective for absorbing and retaining heat.

Thermal Expansion

Thermal expansion refers to the change in size (length, area, or volume) of a substance when its temperature changes. Most materials expand when heated and contract when cooled, although the degree of expansion varies depending on the material. The reason behind this is that heating increases the average kinetic energy of the particles in the material, causing them to move more and occupy more space.

Types of Thermal Expansion

1. **Linear Expansion**: This occurs when the change in temperature affects the length of an object. The change in length (ΔL) is directly proportional to the initial length (L_0) and the change in temperature (ΔT). The formula is:

   $\Delta L = L_0 a \Delta T$

   - a is the linear coefficient of thermal expansion, which varies for different materials.

2. **Area Expansion**: When the surface area of an object changes due to temperature, it is known as area expansion. The change in area (ΔA) is given by:

   $\Delta A = A_0 \beta \Delta T$

   - B is the coefficient of area expansion, and $\beta = 2a$.
3. **Volume Expansion**: This is the expansion in three dimensions, where the volume of an object changes. The change in volume (ΔV) is given by:

   $\Delta V = V_0 \gamma \Delta T$

   - γ is the coefficient of volume expansion, and $\gamma = 3a$.

Coefficients of Thermal Expansion

Different materials have unique coefficients of thermal expansion. For example, aluminum has a higher linear expansion coefficient than copper, meaning it expands more for the same temperature change.

Examples of Thermal Expansion

- **Steel Bridge Example**: A steel bridge built in segments has a gap to allow for expansion due to temperature increases. If a gap of 4 cm is left between segments, it can handle a temperature increase of 180°C before the bridge buckles.
- **Brass Plate Example**: A circular brass plate with an area of 3850 cm^2 at 100°C contracts to 3835.37 cm^2 when cooled to 0°C. This is important in applications like fitting components together where precise measurements are crucial.

Applications of Thermal Expansion

1. **Riveting**: Metal rivets are heated, expanded, and then cooled to create a tight fit between metal sheets.
2. **Bimetallic Strips**: Used in thermostats, these strips are made of two metals with different expansion rates, causing the strip to bend when heated.
3. **Thermometers**: Use the expansion of mercury or alcohol to measure temperature changes.
4. **Glass Bottles**: Slight heating can help remove tight stoppers from bottles due to the expansion of the neck of the bottle.

This concise note covers key concepts of thermal expansion and provides practical examples and questions for understanding.

5.5 Change of Phase

Understanding Matter and Phases

Matter, which includes everything that has mass, exists in different forms called phases or states, such as solid, liquid, and gas. These phases can change into one another when heat is added or removed. For example, water can be found as ice (solid), liquid water, or steam (gas) depending on the temperature.

What is a Phase Change?

A phase change occurs when a substance changes from one state of matter to another. During this change, the temperature remains constant, but the internal energy of the substance changes. This energy is used to alter the molecular structure, breaking or forming bonds between molecules. Examples of phase changes include:

- **Melting**: Solid to liquid
- **Evaporation**: Liquid to gas

Latent Heat

Latent heat is the energy absorbed or released by a substance during a phase change without changing its temperature. The formula to calculate the energy required for a phase change is: $Q=mL$ Where:

- Q is the heat energy (in joules),
- m is the mass (in kilograms),
- L is the latent heat of the substance (in joules per kilogram).

There are two types of latent heat:

- **Latent Heat of Fusion (L_f)**: The energy required to change a solid into a liquid without changing its temperature (e.g., ice melting into water).
- **Latent Heat of Vaporization (L_v)**: The energy required to change a liquid into a gas without changing its temperature (e.g., water boiling into steam).

The term "latent" means "hidden" because this heat does not change the temperature but is used to break the bonds between molecules.

- The formula used is:

$$m_i L_f + m_i c_i (T_f - T_{0i}) = m_w c_w (T_{0w} - T_f) + m_c c_c (T_{0w} - T_f)$$

where:

- m_i = mass of ice
- L_f = specific latent heat of fusion of ice
- c_i = specific heat capacity of ice
- T_f = final temperature
- T_{0i} = initial temperature of ice
- m_w = mass of water
- c_w = specific heat capacity of water
- T_{0w} = initial temperature of water
- m_c = mass of calorimeter
- c_c = specific heat capacity of calorimeter

Phase Diagram

A phase diagram is a graph that shows the state of a substance at various temperatures and pressures. The diagram has three main curves representing boiling, melting, and sublimation points. As you cross these curves, a phase change occurs.

- **Triple Point**: The point on the phase diagram where all three phases (solid, liquid, gas) coexist in equilibrium.
- **Critical Point**: The highest temperature and pressure at which a substance can exist as a liquid. Beyond this point, the substance becomes a supercritical fluid, where liquid and gas phases merge.

Calorimetry

Calorimetry is the measurement of heat transfer during chemical reactions or phase changes. A calorimeter is a device used to measure the specific heat capacity or latent heat of substances.

Measuring Specific Heat Capacity

To measure the specific heat capacity of a substance, you need to know:

- The mass of the substance
- The amount of heat energy supplied
- The starting and final temperatures

The specific heat capacity is calculated using the formula: $Q = mc\Delta T$ Where:

- Q is the heat energy (in joules),

- m is the mass (in kilograms),
- c is the specific heat capacity (in joules per kilogram per degree Celsius),
- ΔT is the temperature change (in degrees Celsius).

There are different methods to measure specific heat capacity:

- **Electrical Heating Method**: Using an electric heater to supply energy to a substance and measuring the resulting temperature change.
- **Mixture Method**: Mixing a hot substance with a cold one and measuring the temperature change to determine the specific heat capacity.

Real-Life Applications of Specific Heat

- **Cooking Utensils**: Made of materials with low specific heat to heat up quickly, such as aluminum or copper.
- **Insulators**: High specific heat materials, like wood, are used in construction to maintain stable temperatures in homes.
- **Climate**: The high specific heat of water helps regulate the Earth's climate by absorbing and releasing heat slowly, leading to more stable temperatures.

Understanding the change of phase and specific heat capacity is crucial for various practical applications in everyday life and scientific research.

Measuring Specific Latent Heat

Specific latent heat is the amount of heat required to change the state of a unit mass of a substance without changing its temperature. It can be measured using different methods, including the electrical method and the method of mixture.

1. Electrical Method

- **How it works**: Energy is supplied to a substance for a known period using an electrical heater of known power. The amount of energy supplied is calculated, and from this, the specific latent heat can be determined.

2. Method of Mixture

- **How it works**: A calorimeter is used to mix known quantities of water and ice. The heat lost by the water (and calorimeter) is equal to the heat gained by the ice, which includes both warming the ice to its melting point and then melting it. The specific latent heat of ice can be determined using the following steps:

Applications of Latent Heat in Daily Life

- **Steaming Food**: Uses the latent heat of vaporization.
- **Cooling Drinks with Ice**: Involves the latent heat of fusion.
- **Extinguishing Fire with Water**: Uses the high latent heat of vaporization of water.
- **Melting Ice on Roads with Salt**: Involves the process of freezing point depression.