Chapter 5 Heat and Temperature

1 Introduction

Heat and temperature are fundamental concepts that play a crucial role in our understanding of the physical world. From the simple act of boiling water to the complex mechanisms powering engines and climate systems, heat and temperature govern various processes and phenomena. In this chapter, we delve into the nature of heat and temperature, exploring their definitions, measurement, and applications across diverse fields.

Though related and frequently used interchangeably, from a scientific perspective – heat and temperature are actually very different concepts. Thus, we will begin our exploration of the concepts by establishing a clear understanding of the meaning of heat and temperature. Let's first look at temperature. In scientific terms, temperature is a measure of the average kinetic energy of all the particles within a substance or system and provides the driving force for the transfer of heat. *The **temperature** of an object quantifies the degree of hotness or coldness of an object*. Conversely, heat is the total internal energy of a body and always flows spontaneously from hotter regions to cooler regions which equalizes temperatures and establishes thermal equilibrium. **H*eat*** is defined as *the transfer of energy from one object or system to another due to a difference in temperature.*

A conceptual grasp of heat and temperature is essential across various scientific and technological domains. These concepts are very important because they serve as the foundation for understanding heat transfer and energy conversion processes which are required for designing efficient engines and power plants, developing sustainable heating and cooling systems, understanding weather patterns and climate change, and monitoring temperature during medical procedures. Beyond specialized fields, heat and temperature impact our daily lives. We rely on them to maintain comfortable room temperatures, cook our food, and provide hot water for our daily needs. So, an awareness of heat transfer mechanisms and energy consumption can allow us to make informed decisions regarding insulation, energy efficiency, and sustainable practices.

In this chapter, we will explore heat and temperature. We will examine temperature scales and measurement techniques, energy efficiency and the mechanisms of heat transfer as we explore their applications and develop a deeper understanding of the world around us.

5.2 The Kinetic Molecular Theory of Matter

In order to better understand the concepts, it may be necessary to examine how matter is structured at the molecular level since this is fundamental to understanding how matter behaves. The notion that matter is not comprised of continuous elements (water, air, earth and fire) but of tiny particles called atoms and molecules[1] has been accepted by the scientific community for centuries. Atoms are the smallest unit of matter and they combine to form molecules. The relationship between the atoms and molecules that make up matter and heat and temperature is well established in the literature. Universally known as the **kinetic molecular theory of matter**, this theory *that matter is made up of atoms in constant motion* which determines the physical properties of objects. It also provides a framework for understanding how materials behavior at different temperatures and the different states of matter.

At the molecular level, the kinetic energy of the constantly moving atoms causes atoms and/or molecule to interact with each other. The amount of kinetic energy in the object or system determines not only the temperature but the **phases** or different physical states in which matter can exist but how it transitions between the different phases. While several phases or states of matter are known to exist, only four are observable in everyday life: solid, liquid, gas, and plasma. Of these only solids, liquids and gases exist freely on Earth.

5.3 Phases of Matter

5.3.1 Solids

In solids, atoms and/or molecules are closely packed together in ordered arrangements. Because of this, the inter-molecular forces in a solid tend to be very strong and so the particles in a solid can only vibrate around their fixed positions within the structural arrangement of a substance. This results in *solids having a fixed shape and volume.*

5.3.2 Liquids

While molecules in liquids have more kinetic energy and move faster than in solids which results in a less ordered structure, the intermolecular forces serve to keep the molecules relatively close to each other. So, although a liquid will take the shape of any container in which it is placed, the intermolecular forces between its molecules are strong enough for the liquid to retain its volume. Consequently, *liquids have a definite volume but no definite shape*.

5.3.3 Gases

Compared to solids and liquids, the molecules in gases have a lot of kinetic energy so are highly energetic and move quickly and randomly. This causes wide separation of the molecules and serves

[1]It is important to note here that atoms combine in small whole number ratios to form molecules.

to greatly weaken the intermolecular forces; as such, a gas will uniformly fill any container in which it is placed. Thus, *gases have neither a fixed shape nor a fixed volume.*

5.3.4 *Plasma*

When matter is superheated or heated to extremely high temperatures, it vaporizes, the electrons in the atoms of the resulting gas are ripped away from their nuclei and the gas becomes ionized or charged. When a gas becomes electrically charged it becomes plasma. NASA estimates that around 99.9 % of the visible universe - the night sky - is actually made up of glowing plasma. This includes the corona[2] of our sun (the source of all our energy), all the stars, nebulas and auroras in the sky. Although plasma does not exist freely on Earth, it does exist in common sources including fluorescent and neon lights, plasma televisions and lightening during thunderstorms. Plasma is also used in several applications including the manufacture of computer chips and for rocket propulsion.

5.3.5 *Fluids*

Fluids are defined as substances that flow without deforming under a force and take the shape of any container in which they are placed. Liquids, gases and plasma are classified as fluids; however, because solids do not flow, they are not included in this classification.

5.4 Temperature

As mentioned above, temperature is defined as the degree of hotness or coldness of an object. In other words, the temperature of an object is a physical quantity that tells us how hot or cold an object is. While we all have some idea what these terms mean, simply expressing a temperature as hot or cold is not very informative, not only because it is imprecise but because it can be quite subjective. For example, have you ever been in a room where you were hot but the person sitting next to you was cold or comfortable? So, because we, as humans, tend to sense things differently, personal definitions of hot or cold are unreliable and therefore it became necessary to find a more precise way to measure temperature.

Recognizing the need for reliable estimates, ancient civilizations began utilizing the expansion and contraction of substances to evaluate changes in temperature. In 1593, an Italian scientist by the name of Galileo Galilei (1564 -1642) invented the thermoscope - the first formal device to shown temperature changes. In 1612, Santorio Santorio (1561 – 1636) applied a scale to Galileo's

[2] The outermost layer of the sun.

thermoscope creating the **thermometer**. A t*hermometer is a device used to measure temperature*. Thermometers function by relying on the physical properties of substances that change with temperature such as the expansion of liquids or gases, the change in electrical resistance of metals, or the emission of thermal radiation.

In this section, we will delve into the different temperature scales and measurement techniques that allow us to quantify and compare temperatures accurately. Understanding temperature scales and their conversions is essential for effective communication and analysis of thermal phenomena.

5.5 Temperature Scales

As with any measurement, a standard unit or referent is necessary to provide a frame of reference for precisely quantifying, expressing, standardizing and comparing temperature values. In this regard, there are three commonly used temperature scales: Fahrenheit (°F), Celsius (°C) and Kelvin (K).
The Fahrenheit scale, commonly used in the United States, was developed by German physicist Daniel Gabriel Fahrenheit (1686 – 1736) around 1714. Fahrenheit defined the lower extent or zero point of his scale using a brine solution made up of water, ice and salt (0°F) and the upper limit as average human body temperature (96°F). The Fahrenheit scale (°F) has since been refined to include the freezing point (32°F) and boiling point (212°F) of pure water at standard atmospheric pressure. Although less prevalent globally, it is still utilized in specific contexts, such as weather reporting in the United States.

Anders Celsius (1701–1744) is credited with developing the more frequently used Celsius temperature scale in 1742. The Celsius scale, also known as the centigrade scale, is based on the properties of water. It sets the freezing point of water at 0°C and the boiling point at 100°C under standard atmospheric pressure. The Celsius scale is widely used in everyday life and many scientific applications.

The Kelvin scale is an absolute temperature scale. Developed in 1848 by William Thomson, Lord Kelvin (1824 – 1907), the Kelvin scale begins at absolute zero. *Absolute zero is defined as the lowest theoretically achievable temperature where molecular motion ceases*. On the Kelvin scale, absolute zero is defined as 0 K, and temperature increments are equivalent to those on the Celsius scale. Because of its ability to measure temperatures below the freezing point of both the Fahrenheit and Celsius scales, the Kelvin scale is frequently used in scientific and engineering calculations, particularly thermodynamics, because it avoids the use of negative temperature values. Unlike the Fahrenheit and Celsius scales, measurements in the Kelvin scale are called kelvins and so the Kelvin scale does not utilize the degree symbol.

Because there are 180 degrees and 100 degrees between the boiling and freezing points of water on the Fahrenheit and Celsius scale respectively, it is frequently necessary to convert between the two temperature scales for seamless communication and compatibility across the two systems. Conversion formulas exist to convert temperatures from one scale to another. For example, the conversion formulas between Celsius and Fahrenheit are:

$$°\mathrm{F} = \left(°\mathrm{C} \times \frac{\mathbf{9}}{\mathbf{5}}\right) + \mathbf{32}$$

$$°\mathrm{C} = (°\mathrm{F} - \mathbf{32}) \times \frac{\mathbf{5}}{\mathbf{9}}$$

The kelvin scale is based on the Celsius scale so one kelvin is the same size as a degree on the Celsius scale. However, since the Kelvin scale begins at absolute zero which measures - 273 ℃ on the Celsius scale, conversion from Kelvin scale is as follows:

$$\boldsymbol{K} = \ °\mathrm{C} + \mathbf{273}$$

Exercise:

According to the World Health Organization (WHO), when the maximum temperature at a weather station in a plain or broad area of relatively flat land reaches 40°C, the area is undergoing a heatwave. Express this temperature in (a) degree Fahrenheit and (b) Kelvin.

(a) Convert to °**F**

Convert *40°C to °F*:

$$°\mathrm{F} = \left(°\mathrm{C} \times \frac{9}{5}\right) + \mathbf{32°}$$

$$°\mathrm{F} = \left(40°\mathrm{C} \times \frac{9}{5}\right) + 32° = \ 72° + 32° = \underline{\underline{\mathbf{104\ °F}}}$$

(b) Convert to K

$$K = \ °\mathrm{C} + 273$$

$$\mathrm{K} = 40\ °\mathrm{F} + 273 = \underline{\underline{\mathbf{313\ K}}}$$

5.6 Thermometers

To ensure reliable results, accurate and precise temperature measurements are vital for scientific research, industrial processes, medical and everyday applications. Thermometers measure temperature by using thermal expansion, where the volume or length of a substance changes with temperature. Liquid-in-glass, digital and infrared thermometers are among the most widely used types. Each has its advantages that makes it suitable for specific applications.

5.6.1 Liquid-in-glass thermometers

Liquid-in-glass thermometers are a traditional type of thermometer consisting of a glass tube filled with a liquid (such as mercury or alcohol) and a calibrated scale. As the temperature changes, the liquid expands or contracts, causing it to rise or fall within the narrow tube, indicating the temperature. Towards the end of the 20th century, upon the recommendation of the medical society, most countries began to phase out the use of mercury thermometers because mercury is highly toxic. By around 2012, mercury was no being longer used in medical thermometers. Now, except for scientific research and in fields such as in meteorology, alcohol thermometers are now used.

Liquid-in-glass thermometer

5.6.2 Digital and Infrared thermometers

Digital thermometers use electronic sensors to measure temperature. The sensor converts the temperature into an electrical signal, which is then processed and displayed as a numerical value on a digital screen.

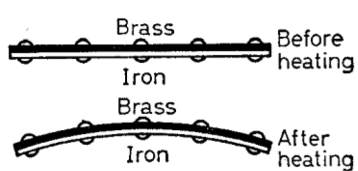
Digital thermometer

Infrared thermometers measure temperature by detecting and measuring the thermal radiation emitted by an object. The infrared detector is sensitive to infrared radiation and converts the received radiation into a temperature reading. Thus, infrared thermometers can measure the temperature of an object temperature without physical contact.

Infrared thermometer

5.6.3 Bimetallic Thermometers

The Bimetallic strip was invented in 1759 by John Harrison (1693 - 1776), a British clockmaker. A bimetallic strip is a temperature-sensitive device consisting of two different metals bonded together to form a coil or strip. The metals used are typically brass and steel, which have different coefficients of thermal expansion or expand at different rates when heated.



Bimetallic Strip (*credit About Science - Science Universe*)

When a bimetallic strip is subjected to a change in temperature, the different expansion rates of the two metals cause the strip to bend or deform. This bending occurs because each metal expands or contracts at a different rate in response to temperature changes. The degree of bending is proportional to the temperature change and the temperature can be read from a calibrated scale.

Bimetallic strips are commonly used in various applications, such as in thermostats, temperature switches, and thermal protection devices. In thermostats, for example, the bimetallic strip is used to control the opening and closing of electrical contacts based on temperature changes. When the temperature rises or falls beyond a certain set point, the strip deforms and either makes or breaks the electrical contact, thereby regulating the temperature. This is what causes air conditioners and convection ovens to cycle on and off. Overall, bimetallic strips provide a simple and effective means of converting temperature changes into mechanical motion or electrical signals.

Bimetallic Thermometer (*credit About Science - Science Universe*)

5.7 Thermal Expansion and Contraction

When materials are exposed to changes in temperature, they undergo changes in dimensions, leading to expansion or contraction. Understanding these processes is critical for numerous applications, from building bridges to designing intricate electronic systems. Thermal expansion occurs when materials expand in size as its temperature increases. The extent of expansion depends on the material's coefficient of thermal expansion, which quantifies the fractional change in size per degree of temperature change. Different materials exhibit varying coefficients of thermal expansion due to differences in atomic structure and bonding.

Materials can undergo linear and or volumetric expansion. Linear expansion describes the change in length and volumetric expansion the change in volume a material undergoes as the temperature increases or decreases. Most substances expand when heated and contract when cooled.
The coefficients of linear expansion and volumetric expansion is a measure of this change per degree change in temperature. Thermal expansion and contraction have practical implications in engineering and construction. For example, when designing structures such as bridges or railways, engineers must account for the expansion and contraction of materials due to temperature variations to prevent structural damage or deformation.

Thermal expansion is also significant in everyday life. The expansion and contraction of materials in response to temperature changes are harnessed in systems like thermostats and expansion joints to ensure proper functioning and avoid damage. An understanding of thermal expansion and contraction is essential to engineers, designers, and scientists so they can account for the effects of temperature changes on materials and develop robust systems and structures.

Walkway with Thermal Expansion Slots

5.8 Heat

Heat is a fundamental concept in our understanding of energy transfer and the behavior of matter. Historically, the concept of heat has evolved over centuries of scientific inquiry. Early theories viewed heat as a substance called "caloric" that flowed from hot objects to cold objects. However, with advancements in understanding, heat is now recognized as a form of energy transfer rather than a physical substance. Heat is the foundation of the study of thermodynamics. It can best be defined *as a form of energy that is transferred between objects or systems as a result of temperature differences*. While we hold a conceptual understanding of heat, a thorough understanding of this concept requires us to examine heat from a microscopic perspective.

At the microscopic level, heat is associated with the total internal energy and the random motion of the atoms and molecules within a substance. With heat is added to a substance, the kinetic energy of its particles increases leading to an increase in temperature. Heat and temperature are related concepts; however, there are very distinct concepts in physics and thermodynamics. While temperature measures the average kinetic energy, heat is a measure of the total internal energy of an object. Thus, heat can cause changes not only in the temperature of an object but also in its phase.

Because heat is a form of energy, the standard unit of measurement for heat in the SI (Système International de Unites) or metric system is the Joule (J). However, the more familiar calorie (cal) and British thermal unit (BTU) are also commonly used. A *calorie (cal) is defined the amount of energy required to raise the temperature of one gram of water by 1 degree Celsius*. It is important to note here that calories as defined above as not the same as Calories listed on US food packaging. In the case of food items, the energy provided is measured in kilocalories and thus, a food Calorie is equal to 1,000 calories. To differentiate between the two values, the first letter of the food calorie is always capitalized and written as **C**alorie while the first letter of the defined **c**alorie is not.

1 cal = 4.186 J
1 kcal = 4186 J
1 kcal = 1 Cal = 1000 cal

5.8.1 Specific Heat

Heat capacity and specific heat are closely related to the thermal properties of substances and their response to changes in temperature. Heat capacity depends on the mass and composition of a substance and is the total amount of heat energy needed to produce a given change in temperature. The specific heat capacity of an object is its heat capacity per unit mass. Essentially, it is a measure of the amount of heat that would be required to raise the temperature of an object by a specific amount. The specific heat of an object or system is defined *as the amount of heat required to raise the temperature of the object by 1°C.* Specific heat is denoted by the letter "**c**" and typically measured in calories per kg degree Celsius (cal/kg °C, joules per kg degree Celsius (J/kg °C), joules per kg Kelvin (J/kg K) though calories per gram degree Celsius (cal/g °C) and joules per gram degree Celsius (J/g °C) are also frequently used. Specific heat is very useful for comparing the thermal behavior of different materials.

Substance	**cal/g °C**	**J/g °C**
Aluminum	0.214	0.890
Copper	0.092	0.385
Gold	0.129	0.030

Iron	0.106	0.442
Mercury	0.140	0.030
Silver	0. 235	0.057
Water	1.000	4.184
Ice	0.499	2.089
Steam	0.480	2.030
Lead	0.030	0.129

Specific Heat Capacities of some Common Substances

Numerous industrial processes require accurate assessments of the total heat requirements. While there are typically large-scale operations, it may surprise you to know that we conduct small-scale heat calculations not just everyday but all day long. As a matter of fact, it is so much a part of our everyday life that we conduct heat requirement analyses with very little conscious thought in simple everyday applications. For example, whenever we use a microwave oven to reheat a meal – we select the amount of time needed based on a quick assessment of the contents and size of the meal and by how much we need to increase the temperature. Failure to not consider any of these three factors will result in our meal either being undercooked or burnt to a crisp.
As you can see from the example above, the quantity of heat required to raise the temperature of an object is directly related to its mass. As the mass of an object increases, the total amount heat required to raise its temperature also increases; however, since specific heat is intrinsic and a function of its structure and composition, an object's specific heat remains constant. Therefor to reliably estimate the total quantity of heat required to change the temperature of an object, one must consider the following three factors: the specific heat of the object **c**, the mass of the object **m** and the difference in temperature **ΔT**.

The relationship can be summarized in the following equation:

$$Q = mc\Delta T$$

Where ***Q*** is the total amount of energy transferred, ***m*** is the mass of the substance, ***c*** is the specific heat capacity and ***ΔT*** is the temperature change.

Exercise:

How much energy is required to raise the temperature of 100.0 g of gold from 25° C to 95° C?

Given:

Mass of gold	m = 100.0 g
Initial Temperature	T_i = 25 °C
Final Temperature	T_f = 95 °C
Find Energy	Q = ?
Solution:	Q = mc ΔT
	Q = 100.0 g × 0.129 cal/g°C × (95°C - 25°C)
	Q = 903 cal

5.9 Heat Transfer

5.9.1 Laws of Thermodynamics

The fundamental principles that govern energy and heat transfer in physical systems are summarized into three laws. The three laws of thermodynamics provide a framework for understanding and describing the behavior of energy and heat transfer in various forms including heat, work and internal energy.

The ***first law of thermodynamics,*** also known as the **Law of Conservation of Energy,** states that the total amount energy within a system remains the same. This means that *energy can neither be created nor destroyed; it is only converted from one form to another or transferred from one system to another.*

The ***second law of thermodynamics*** is known as the **Law of Entropy**. In its simplest form, this law essentially says that *heat always flows spontaneously from regions of higher temperature to regions of lower temperature.*

The ***third law of thermodynamics*** states that *the closer a system gets to absolute zero (0 K), the more difficult it becomes to extract energy.*

5.9.2 Transfer of Heat

As discussed above, heat moves spontaneously from regions of higher temperature to regions of lower temperature and is the transfer of heat can occur through three fundamental mechanisms: conduction, convection, and radiation.

Conduction is the transfer of heat through direct contact between particles within a substance or between substances in contact. In solids, heat is primarily transferred through atomic or molecular collisions. At the microscopic level, as high-energy particles collide with neighboring particles, the energy is transferred from one particle to another which raises the overall kinetic energy levels. The rate at which materials transfer heat by conduction depends on several factors including temperature difference, the area of contact, the thickness of the medium and the thermal conductivity or ability to conduct or transfer of the materials involved. Materials with high thermal conductivity, such as metals, allow efficient heat conduction.

Convection involves the transfer of heat through the movement of fluid (liquid or gas) particles. Convection can occur naturally (natural convection) or aided by external means (forced convection). In natural convection, the movement arises from the differences in density that are caused by variations in temperature. During heat transfer by convection, as fluids heat up, they expand and density decreases causing the hot fluids rise. As the hot fluids rise, the cooler fluids sink taking their place which creates a circulation pattern. In forced convection, external devices, such as fans or pumps, enhance fluid motion, leading to increased heat transfer rates. Natural convection controls our weather patterns including wind flow whereas forced convection is used in appliances such as space heaters and convection ovens.

Radiation is the transfer of heat through electromagnetic waves. Unlike conduction and convection, radiation does not require a medium for energy transfer. Instead, it occurs through the emission and absorption of electromagnetic waves, such as infrared radiation. All objects above absolute zero (0 K) emit thermal radiation, and the intensity of radiation depends on the temperature and surface properties of the object.

5.10 Thermal Conductors and Insulators

With respect to the transfer of heat, materials can also be classified based on their ability to conduct heat. Materials with high thermal conductivity or materials that readily allow heat to flow through them called conductors. Conductors efficiently transfer heat because their structure allows the molecules within the material to vibrate rapidly. Metals such as copper, aluminum, silver, and gold are excellent thermal conductors. Conversely, materials that resist the flow of heat or have low thermal conductivity are known as insulators. Insulators are poor conductors of heat because their structures often contain air pockets or low-energy molecular bonds that restrict or hinder heat flow.

Materials such as wood, rubber, plastic, glass, and ceramic are good insulators of heat. Overall, heat conductors are used for efficient heat transfer in applications requiring high thermal conductivity, while insulators are employed to minimize heat loss or heat gain by providing thermal insulation.

Understanding the mechanisms of heat transfer allows us to analyze and optimize energy transfer processes. Each heat transfer mechanism has unique characteristics and applications. Conduction plays a crucial role in thermal management and energy-efficient design in solids such as in the construction of buildings, while convection is essential in various natural and industrial processes, including heat exchangers and cooling systems. Radiation is the primary mode of heat transfer from the Sun and in applications such as thermal imaging and heating systems.

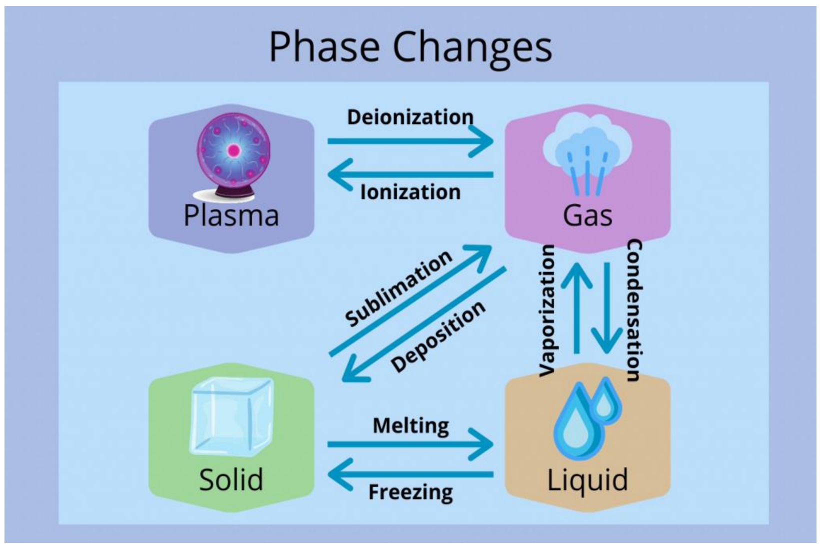
5.11 Phase Changes

Phase changes or transitions occur when substances undergo a transition from one state (or phase) to another due to changes in temperature or pressure. Understanding phase changes is crucial in various fields, including thermodynamics, materials science, and engineering, as it affects processes such as heating, cooling, phase separation, and phase equilibria. As previously discussed, the most common phases of matter on Earth are solid, liquid, and gas. We will now take a moment to explore the different types of phases and how they change from one phase to the other.

When a solid is heated, it absorbs heat energy and the temperature increases. At the molecular level, the kinetic energy increases to the point where the atoms and molecules have enough energy to begin breaking the bonds that hold the solid lattice structure together. As the lattice structure falls apart, the particles transition into a disordered arrangement or changes from a solid to a liquid. This process is called **melting** and the point at which the structural bonds begin to break is known as the melting point. The reverse occurs as a liquid cool down or loses heat. As the temperature decreases, the particles slow down and arrange themselves into a more ordered, closely packed structure, forming a solid. This process is called **freezing** and the point at which the structural bonds begin to reform is known as the freezing point.

Vaporization, or evaporation, is the phase change from a liquid to a gas state. It occurs when a liquid absorbs enough heat energy to reach its boiling point. At the boiling point, the liquid particles have sufficient energy to overcome intermolecular forces that causes a liquid to be able to retain its volume and transform from a liquid into a gas. **Evaporation** is process of changing a liquid to a gas. The reverse occurs when a gas cools or loses enough heat energy to reduce its temperature to below its boiling point. The gas particles slow down and move closer together, this results in the formation of liquid droplets. The phase change from a gas to a liquid state is called **condensation**.

Sublimation is the phase change from a solid directly to a gas without passing through the liquid phase. It occurs when a substance absorbs sufficient heat energy, bypassing the melting process. The solid particles gain enough energy to transition into a gaseous state. And **deposition** is the phase change from a gas directly to a solid without passing through the liquid phase. It occurs when a substance loses heat energy, bypassing the condensation process. The gas particles lose energy and arrange themselves into a solid structure.



Phase Change Diagram (*credit*: sciencenotes.org)

It is important to note that during phase changes, the absorbed or released heat energy is used to break or form intermolecular bonds within the substance. Consequently, the temperature of an object does not increase during a phase change and while phase changes involve the transfer of heat energy, they do not cause a change in temperature. The heat energy that is absorbed or released during a phase change without a change in temperature is referred to as the latent heat. **Latent heat** *is the energy required to change the phase of a substance, such as from solid to liquid or from liquid to gas, while keeping the temperature constant.* There are two types of latent heat associated with changes in phases: the latent heat of fusion and the latent heat of vaporization.

The **latent heat of fusion** *is the amount of heat energy required to change a unit mass of a substance from the solid phase to the liquid phase or from liquid to solid phase*. During melting, the solid absorbs heat and gains enough energy to break apart the intermolecular bonds and transition into a liquid state. In freezing, heat is released as the liquid loses energy and forms a solid. The amount of energy required to break or form the intermolecular bonds is called the latent heat. Latent heat does not result in a change in temperature because the during the phase change, all the heat energy gained or lost by the object is utilized in the formation or destruction of its internal structural bonds and does not contribute to the average kinetic energy of the molecules. The latent heat of fusion is denoted by the symbol $\mathbf{L_f}$.

The **latent heat of vaporization** *is the amount of heat energy required to change a unit mass of a substance from the liquid phase to the gaseous phase or vice versa*. During evaporation, heat is absorbed as the liquid gains energy to break the intermolecular bonds and transform into a gas and the heat released as the gas loses heat energy and condenses into a liquid. Similar to the latent heat of fusion, the substance absorbs or releases heat energy during this phase change without a change in temperature. The latent heat of vaporization is denoted by the symbol $\mathbf{L_v}$.

Like specific heat, the latent heat constants depend on factors such as the nature of intermolecular forces and the strength of the bonds between molecules and are specific to each substance. Latent heat values for the commonly encountered substances are provided in Table 4.2. The ability to reliably estimate latent heat quantities is imperative to field such as refrigeration and heating. Latent heat quantities are calculated using the equations below:

The Latent Heat of Fusion: $\mathbf{Q = mL_f}$

The Latent Heat of Vaporization: $\mathbf{Q = mL_v}$

Where **Q** is the quantity of heat energy, **m** is the mass of the substance, $\mathbf{L_f}$ is the latent heat of fusion and $\mathbf{L_v}$ is the latent heat of vaporization.

Exercise:

How much energy is absorbed to convert 10.0 g of ice at - 5° C to water at room temperature? Assume room temperature is 20° C.

Given:
Mass $m = 10.0$ g
Initial Temperature $T_i = -5$ °C
Final Temperature $T_f = 20$ °C

Find Energy Q = ?

Solution:
The process of converting the ice to water involves 3 separate steps:

1. the energy required to raise the temperature of the ice to melting point.
2. the energy required to melt the ice.
3. the energy required to raise the temperature of the water to room temperature.

And the total energy required will be the sum of energy required at each individual step.

Step 1: Calculate the energy required to raise the temperature of the ice to melting point:

$Q = mc\,\Delta T$
$Q = 10.0\ g \times 0.500\ cal/g°C \times (0°C - {}^{-}5°C) =$ **25 cal**

Step 2: Calculate the energy required to melt the ice:

$Q = mL_f$
$Q = 10.0\ g \times 80\ cal/g =$ **800 cal**

Step 3: Calculate the energy required to raise the temperature of the water to room temperature:

$Q = mc\,\Delta T$
$Q = 10.0\ g \times 1.00\ cal/g°C \times (20°C - 0\ °C) =$ **200 cal**

Total: Energy at Step 1 + Energy at Step 2 + Energy at Step 3
25 cal + 800 cal + 200 cal = **1025 cal**

5.13 Heat Engines

Heat engines are devices that convert thermal energy into mechanical work. They function based on the laws of thermodynamics which plays a fundamental role in their efficiency and performance. A heat engine typically consists of a heat source where thermal energy is added, a heat sink where thermal energy is rejected, and a mechanism that converts heat energy into useful work. The laws of thermodynamics govern the operation of heat engines and play a fundamental role in their efficiency and performance. The key laws involved are the First Law of Thermodynamics also known as the Law of Energy Conservation. This law states that energy cannot be created or destroyed, but it can be converted from one form to another or transferred between systems. And the Second Law of Thermodynamics or Law of Entropy. The second law sets limits on the efficiency of heat engines. It states that in any cyclic process, the total entropy of an isolated system either remains constant (in reversible processes) or increases (in irreversible processes). This law also provides the basis for the direction of heat transfer from higher temperature regions to lower temperature regions.

Heat engines have widespread applications in everyday life and industrial settings. Some examples include internal combustion Engines, such as those used in automobiles, which convert fuel (chemical energy) into mechanical work through combustion. Gas and steam turbines that operate by converting heat energy into mechanical work and refrigeration and air conditioning systems that utilize compressors and expanders to circulate refrigerants remove heat from a low-temperature region and to a high-temperature region. By understanding the principles of heat engines and their efficiency, engineers and scientists can design and optimize these systems for maximum performance and energy utilization.

5.14 Climate Change and Heat Transfer

Climate change, driven by human activities and the accumulation of greenhouse gases in the atmosphere, has significant implications for heat transfer processes on Earth. The increased concentration of greenhouse gases, such as carbon dioxide and methane, leads to the greenhouse effect which traps more heat in the atmosphere. High levels of heat in the atmosphere alters heat transfer mechanisms and has several negative impacts on the planet. To begin, the increased concentration of greenhouse gases in the atmosphere alters the balance between incoming solar radiation and outgoing thermal radiation which results in a net energy imbalance, or higher overall temperatures. As the ambient temperature increases, the warmer air increases evaporation rates. High evaporation impacts the planet is several ways including increasing the heat and moisture input into the atmosphere which affects ocean currents and heat distribution and altering wind patterns, cloud formation and precipitation distribution which influences regional and global climate patterns.

5.15 Effects of Global Warming on Temperature Distribution

Global warming, a consequence of climate change, has profound effects on temperature distribution across the planet. Some notable impacts include rises in average global temperature and the occurrence of extreme temperatures. Rising average global temperature affects ecosystems, weather patterns, and the frequency and intensity of extreme weather events. Shifts in temperature extremes not only lead to more frequent and intense heatwaves and cold spells, they also impact the rate of ice melt which has very serious implications for sea-level rise and the

stability of polar ecosystems. Overall, the occurrence of the extreme events caused by climate change have implications for human health, agriculture, and natural ecosystems.
Heat transfer processes play a vital role in climate models and predictions. Climate models incorporate equations representing heat transfer mechanisms, such as radiation, conduction, and convection, to simulate the Earth's climate system. By understanding and simulating these heat transfer processes, scientists can use models to make projections about future climate conditions. Climate models consider the Earth's radiation budget, which uses the quantity of sunlight or solar radiation received to estimate changes in temperature which influences cloud formation and affect the balance of incoming and outgoing radiation. The quantity of radiation is also used to estimate greenhouse gas concentrations and determine the heat transfer between the ocean and atmosphere which helps capture phenomena like El Niño and La Niña events, which have significant global climate implications.

5.16 Conclusion

Throughout this chapter, we have explored key concepts related to heat and temperature. We began by defining heat and temperature and highlighting their distinction and relationship. We discussed the molecular theory of matter, which underlies the behavior of substances and their response to heat transfer. We examined the phases of matter, including phase transitions and the importance of understanding them. Furthermore, we delved into heat capacity and specific heat, which quantify the ability of substances to store and transfer thermal energy. We then explored heat transfer mechanisms, including conduction, convection, and radiation. We discussed their principles, applications, and their role in various fields such as energy systems, materials science, and climate science. Additionally, we examined heat engines and their efficiency, highlighting their operation, thermodynamic laws, and real-world applications.

Understanding heat and temperature is crucial in a wide range of scientific and technological fields. These concepts form the foundation of thermodynamics, which governs energy transfer and transformation. Heat and temperature play critical roles in energy systems, climate science, materials science, industrial processes, health, and many other disciplines. They influence the efficiency of systems, the behavior of materials, and the understanding of climate patterns.
To deepen your understanding of heat and temperature, there are several avenues for further exploration and study. Consider exploring advanced topics in thermodynamics, such as entropy, reversible processes, and power cycles. Delve into the principles of heat transfer in specific applications, like renewable energy systems, electronic cooling, or climate modeling. Engage with research on emerging trends, such as nanoscale heat transfer or thermal imaging technologies. Additionally, staying updated on the latest advancements and scientific literature in these areas will contribute to your knowledge and appreciation of heat and temperature.

By continuing to explore these topics, you will gain insights into the fundamental principles governing heat and temperature, their applications, and their role in addressing important challenges, such as climate change and energy sustainability.

Problems:

1. A 150.0-gram block of lead cools from 85°C to 25°C. How much energy was released during this process?
2. How much energy must a refrigerator remove to completely freeze 100 g of room temperature water? (Assume room temperature is 22°C)
3. How much heat is required to convert 250 g of water at 45°C into steam at 100°C
4. A 110.0 g sample of a certain metal warms 25.5 °C when 80.0 calories is added. Calculate the specific heat of this metal?
5. How much heat energy is required to change 2 kg of ice at 0°C into water at 20°C?
6. If 48000 J of heat energy are given off when a 2kg block of metal cools by 12°C, what is the specific heat capacity of the metal?
7. How much heat energy is needed to heat 4.0 kg of aluminum by 8°C?
8. Why is a scald by steam at 100°C much more painful than one by water at 100°C?
9. Frostbite is really a "burn" caused by freezing temperatures. Why does ice burn?
10. What is absolute zero (0 K)? Are there any advantages to having a scale that begins at absolute zero?