Basics of Thermodynamics

Objectives

After going through this module, the learner will be able to

- Understand the basic difference between thermodynamics and mechanics
- Define open, closed and isolated systems.
- Differentiate between adiabatic and diathermic boundaries.
- Define equilibrium state of a thermodynamic system
- State the cause of change in equilibrium state of a system
- Conceptualize thermal equilibrium between two systems and the parameter that characterises it.
- State the Zeroth law of thermodynamics
- Explain how Zeroth law forms the basis of the existence of thermometers.

Content Outline

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Unit Syllabus

Thermodynamics

Thermal equilibrium and definition of temperature (Zeroth law of thermodynamics), heat, work and internal energy. First law of thermodynamics: isothermal and adiabatic processes. Second law of thermodynamics: reversible and irreversible processes, Heat engine and refrigerator.

Module-Wise Distribution of Unit Syllabus - 6 Modules

Module 1	• Thermal equilibrium • Heat exchange • Zeroth law of thermodynamics • Daily life observations
Module 2	• Relation between heat and internal energy • Effect on solids • Effect on liquids • Effect on gases • Work done on and by a system
Module 3	• First law of thermodynamics • Relation between internal energy, work and heat absorbed or released by a body • Relevance of first law to gases • P-V indicator diagram • Thermo-dynamical processes: Isothermal, adiabatic, isobaric, isochoric, reversible and irreversible
Module 4	• Second law of thermodynamics • Heat engines • Carnot cycle • Efficiency of engines
Module 5	• Refrigerator • Heat machines -devices that produce heat geyser, toaster, stove –devices that operate on using internal energy
Module 6	• Understanding the thermal effect of heat and thermodynamics • Problem solving in thermodynamics

Words You Must Know

- **Energy:**Capability of doing work.
- **Temperature:** Degree of willingness of a system to transfer heat to another system. or, the parameter that decides the direction of heat flow between two systems.
- **Heat:** Thermal energy in transit between two systems having different temperatures.
- **Three modes of heat transfer:** Conduction, convection & radiation.
- **Work:** measure of energy transfer that occurs when a force displaces an object in its own direction.
- **Torque:** Turning effect of a force given by $\vec{\tau} = \vec{R} \times \vec{F}$
- **Linear Momentum:** Product of mass and velocity of an object $\vec{P} = m\vec{v}$
- **Mechanical equilibrium:** If both the net external force and torque on a system are zero, the system is said to be in mechanical equilibrium.
- **Point object:** An extended object can be treated as a point object if the distance travelled is much greater than the size of the object.
- **Steady state of heat flow**: When no net heat flows across any cross section of a conductor and the temperature at each cross section does not change with time.
- **Thermometric property:** A property that changes with temperature. e.g. resistance of a wire, volume of a fluid.

Introduction

Thermodynamics is the science of flow of heat. 'Thermo' means heat and 'dynamics' means cause of motion. Thermodynamics deals with concepts of heat, work, temperature and energy. It studies how interconversion between different forms of energy can be made, what the efficiency of such processes is and how they affect matter.

The laws of thermodynamics drive everything that happens in the universe because energy is at the core of every process. Thermodynamics originated in man's endeavor to conquer cold. It developed as a science in the 19th century when scientists first discovered how to build and operate steam engines. After years of work by many scientists, the laws of thermodynamics were established. These laws touch an enormously wide range of phenomena. They can be applied to mechanical systems, chemical systems, nuclear power plants, biological systems, heavenly bodies and even economics.

Thermodynamics is a science based on macroscopic (bulk) properties of matter like pressure, volume, mass, temperature etc. This is because it was developed before people knew about atoms and molecules. Later when scientists learnt about the existence of atoms and molecules, the concepts of thermodynamics could be rationalized using microscopic (molecular level) properties like position, velocity etc. of the constituent molecules of matter. For example, pressure of a gas could be explained in terms of the linear momentum transferred by the gas molecules colliding with the walls of the container.

Mechanics and thermodynamics – both are macroscopic study of sciences. What is the distinction between them? Mechanics is concerned with the external macroscopic state of a body, but thermodynamics is concerned with the internal macroscopic state of the body.

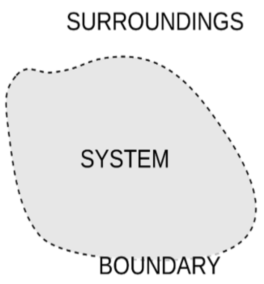
In mechanics, the focus is on motion of a system as a whole, visible as changes in position, velocity etc. In thermodynamics, the focus is on changes happening inside a body manifesting as change in temperature, volume etc. For example, when a moving bullet pierces wood, the changes happening in its velocity and kinetic energy are a concern of mechanics. But the heating of bullets and wood is a concern of thermodynamics.

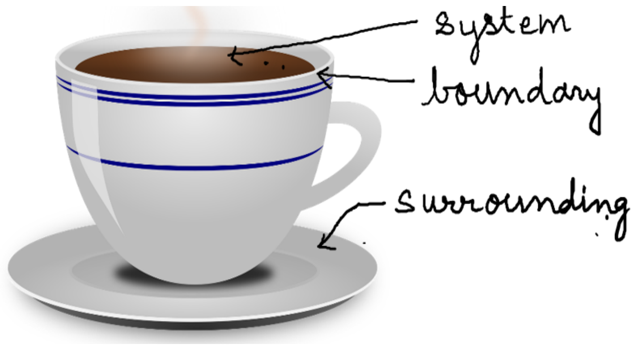
Bullet and wood heat up when the moving bullet pierces wood

Basic Definitions in Thermodynamics

- **Thermodynamic system:** The part of the universe that is the center of attention. It must have a very large number of particles.

  A thermodynamic system can be anything under investigation – coffee in a cup, a pizza being microwaved, air in a room, a human body, a car engine.





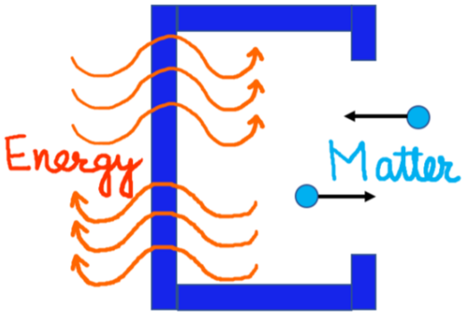
Left Pic: Credit: User: Krauss, Linked source: https://commons.wikimedia.org/wiki/File:System_boundary2.svg#filelinks

Right pic: Public Domain Linked source https://commons.wikimedia.org/wiki/File:Coffee_cup_icon.svg

- **Surroundings**: Everything in the immediate or far environment of the system, which has direct bearing on the thermal behaviour of the system, is called its surroundings. For example, the plate below the coffee cup is part of the surroundings whereas hot coffee in the cup is the system.

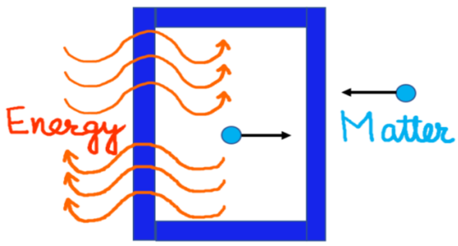
- **Boundary:** The surface separating the system from the surroundings.
  A boundary may be real or imaginary. It may be fixed or movable.
  For example, in the picture the cup forms the real boundary of hot coffee. There is an imaginary boundary on top of the surface of coffee.
  A system is characterized by its boundary because the boundary may or may not allow it to interact with the surroundings.

- **Open system:** An open system can exchange both matter and energy freely with its surroundings.
  The cup of hot coffee is an open system because it loses heat as well as matter to the surroundings in the form of hot vapour, symbolically shown here.



An open system

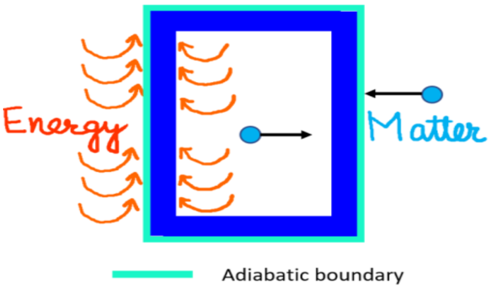
- **Closed system**: A closed system can exchange energy but not matter with its surroundings.



A closed system

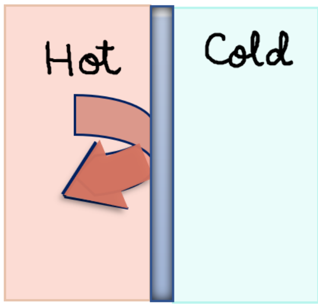
A steel jar with a closed lid containing coffee is a closed system. It can exchange thermal energy with the surroundings but it does not matter.

- **Isolated system**: An isolated system can exchange neither energy nor matter with the surroundings.
  A perfectly isolated system does not actually exist, since energy is always exchanged between a system and its surroundings, although this process may be very slow.
  Hot coffee in an insulated thermos flask closely approximates an isolated system.

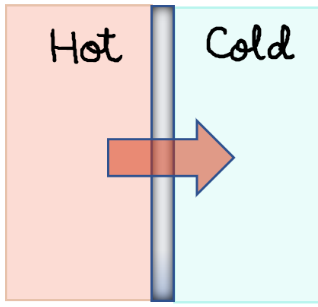


A closed system

- **Adiabatic wall:** A boundary through which heat cannot flow easily. A wooden or a bamboo container, double walled metallic container with air in between the walls with an ebonite handle, almost acts closely as an adiabatic wall.



Adiabatic wall
(passage of heat not permitted)



Diathermic wall
(passage of heat is permitted)

- **Diathermic wall**: A boundary through which heat can flow. A conducting vessel acts as a diathermic wall.

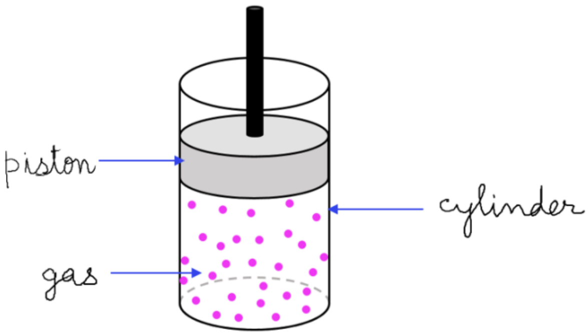
- **Microscopic Variable**: A variable pertaining to the individual atoms and molecules making up the system. E.g.- orientation of a diatomic molecule, speed of a fluid molecule.
- **Macroscopic Variable**: A measurable quantity used to describe the bulk state of a system. It depends on collective behaviour of all the atoms and molecules i.e. on bulk behaviour.
  The macroscopic variables describing the state of a thermodynamic system can be the length of a metallic rod, the electrical conductivity of a wire, the colour of an object, viscosity of a liquid, composition of a gas etc.

- **Thermal interaction**: An interaction in which energy can be exchanged between the system and the surroundings or between two systems.

Example

Because of a great deal of focus on working of engines, scientists are typically interested in the behaviour of a gas confined in a cylinder, fitted with a movable piston. Draw a diagram to show such an arrangement

Solution



Example

Identify the following in the example above:

a) Thermodynamic system
b) The surroundings
c) The Boundary

Solution

a) The gas (since it is the subject of interest).
b) Everything else (including the walls of the cylinder and the piston)
c) The inner surface of the walls of the cylinder along with the lower edge of the piston outlines the boundary of the gas. The piston, moving in and out of the cylinder, forms a flexible boundary.

Example

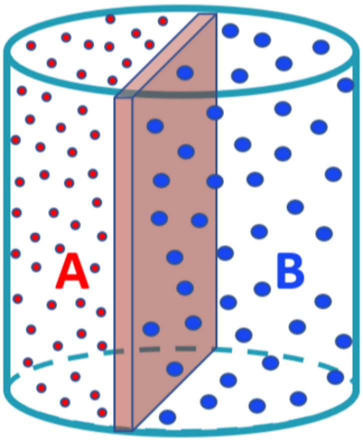
If the side walls of a cylinder containing gas are coated with zirconia ceramics and the bottom is made from a metal, then identify the following in the given situation:

a) A Diathermic Wall
b) An Adiabatic Wall
c) Whether The System Is Open, Closed Or Isolated?

Solution

a) Bottom of the cylinder
b) The side walls of the cylinder, since ceramics are insulators
c) Closed system since the heat, but not matter, can be exchanged between the gas and surroundings through the diathermic bottom.

Example



Two Gases A And B Are Separated By A Diathermic Partition Inside A Sealed Adiabatic Enclosure.

Which Of The Following Are True?

a) A Is An Open System
b) B Is A Closed System
c) Enclosure Containing A And B Is An Isolated System
d) A Is A Closed System

Answer

B), C) and D)

Equilibrium State of a Thermodynamic System

Equilibrium means status quo or the state of no change.

A system is said to be in equilibrium if macroscopic variables describing the state of the system do not change in time and in space.Essentially equilibrium means two things:

a) we can assign a single value to a variable and
b) That value does not change with time.

In mechanics, an object is said to be in equilibrium if its linear and angular velocities/momenta do not change with time, net force and net torque being zero. Can we assign a single value to the velocity of an object when it is made up of so many molecules, all of which are moving? Yes, if all of them move in identical fashion with same velocity such as in linear sliding motion of a block. But can we assign a value of 40 km/h to the velocity of a car moving along a straight road, if different parts move with different speeds e.g. its seat and its tyre? This can be justified only in the situations where the differences can be ignored. This is what necessitated the concept of point object in mechanics.

Now think of a large room with a small table fan running in one far corner. Air is moving in the corner with a fan but there is still air in some other part of the room. Clearly, the pressure of air is not the same everywhere or the pressure keeps changing while being measured. Can we describe the pressure of air in the room by a single number? Obviously, the property must be uniform throughout the system and throughout the measurement time if a single value is to be assigned to it. This is the essence of 'equilibrium' in thermodynamics.

A Thermodynamic System is in

- **Mechanical equilibrium:** When the pressure throughout the system is the same and does not change with time. Pressure is constant when a system does not have any unbalanced force within itself and between the system and its surrounding.

- **Chemical equilibrium**: When composition of the system does not change with time and is same everywhere. This happens when there is no chemical reaction or transfer of matter from the system to surroundings or vice versa.

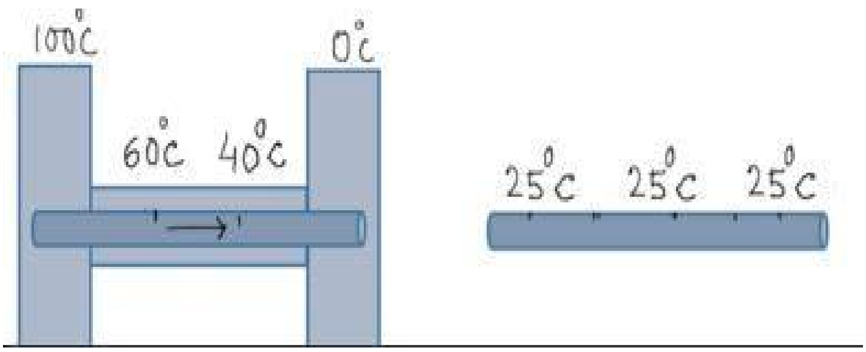
- **Thermal equilibrium**: When the temperature throughout the system is uniform and does not change with time. This happens when there is no transfer of heat from one part to another or between system and surroundings separated by a diathermic wall.
- **Thermodynamic equilibrium:** When all the macroscopic variables do not change with time and in space. A system is in thermodynamic equilibrium only when it is in mechanical, chemical and thermal – all three equilibria simultaneously.

  For example, water boiling continuously in a vessel is in thermal equilibrium but not in thermodynamic equilibrium. An isolated system of gas inside a closed rigid container is in a state of thermodynamic equilibrium because its composition, pressure and temperature are same throughout and none of the macroscopic variables change with time.

  Thermodynamics can deal with systems only if they are in equilibrium state.

  Steady state and equilibrium state
  - A system is said to be in thermodynamic equilibrium if the variables describing the state of the system do not change in time and space.
  - A system is said to be in steady state if the variables describing the state of the system do not change in time but may change with position.

In steady state, different parts of a system may have different values of a variable even though they remain fixed in time but in a particular equilibrium state, the variable has the same value in time throughout the system. Take the example of an iron rod being heated at one end. As heat flows through the rod, initially the temperature at different locations starts rising but after some time, the temperatures at different locations along the length of the rod stop changing. The rod reaches a steady state with highest temperature near the hot end and the lowest at the farthest end. If now the rod is isolated from the heat source and left to its own devices, the hot end cools down and cool end heats up and after a long time, we find the same, unchanging temperature throughout the rod. At this point the rod has attained an equilibrium state.



Example

Thermodynamics can describe a system only if it is in equilibrium, otherwise not because only then

a) A single value can be assigned to a macroscopic variable describing the system.
b) The microscopic variables describing the system have a single value all over the system
c) The microscopic variables assume a single value in time.
d) The microscopic variables are independent.

Answer: (a), (b), (c)

Example

Stainless steel cookware is now available with stainless steel tubular handles. which are sturdy and oven safe? The handles stay cool for a reasonable time during stovetop cooking. Why?

Solution

The Stainless steel handle is formed into a tubular shape, creating an inside air flow up the shank of the handle.

This slows the buildup of heat from the hot pan to the handle. Many product lines with tubular handles also contain a baffle (a sheet to spread the heat, sometimes an opening) where the handle meets the pan, allowing the handle to stay cooler for a longer period of time.

Example

Water is boiling in a steel pan with a steel handle. A student holds it up from the handle, takes it off the gas burner and puts it on the table.

Which of the following is true?

(a) The whole metal vessel can be in steady state but not in equilibrium state

(b) The metal vessel is in equilibrium state but not in steady state

(c) The metal pan is in steady state as well as equilibrium state

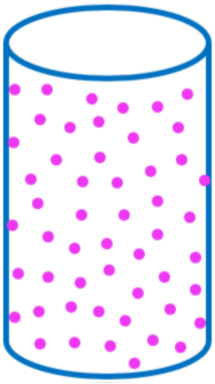
(d) The metal vessel is neither in steady state nor in equilibrium state

Answer: (a)

Change from One Equilibrium State to Another

In mechanics, the equilibrium state of an object changes due to mechanical interaction with the surroundings. The velocity of an object in uniform motion changes when objects in surroundings apply force or exchange energy. In thermodynamics, an equilibrium state of a system changes to another through thermal interaction with the surroundings. The nature of thermal interaction with the surroundings depends on the nature of the boundary between the system and the surrounding.

The equilibrium state of an isolated system remains unchanged. This is because its boundary does not allow any interaction – neither exchange of matter nor energy.

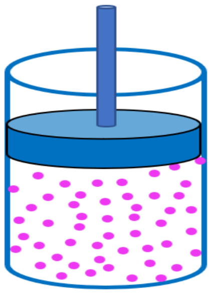


For example, in the figure, a gas is enclosed in a cylinder with rigid adiabatic walls. Experimentally, it is known that the state of a given mass of a gas can be fully described; pressure and volume of a gas can be chosen as two independent variables. Let these parameters be (P, V) for the given gas. Even after a long time we find the gas in the same equilibrium state (P, V).

An equilibrium state of a closed system can change to another because its boundary permits exchange of energy. The exchange can take place through

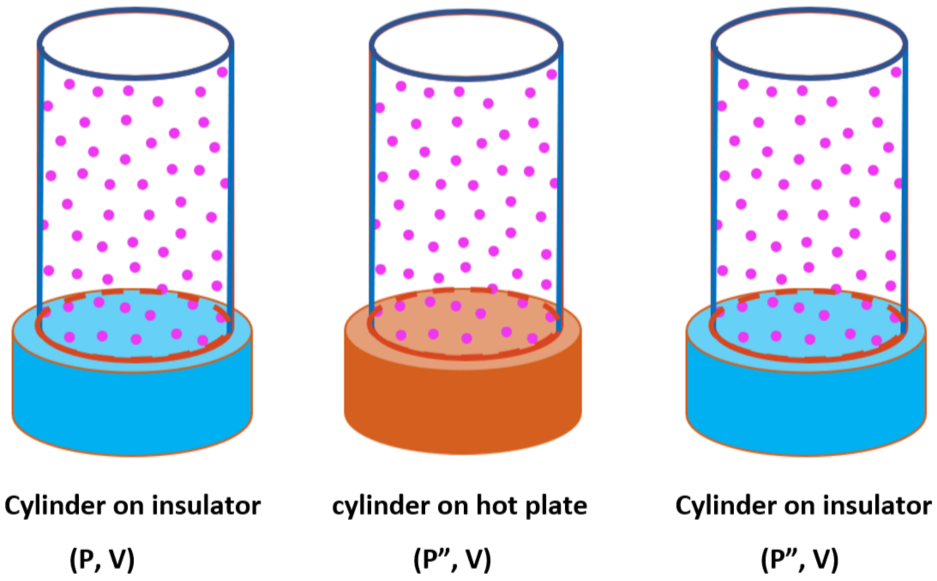
1. Movable boundary
2. Diathermic boundary

A movable boundary enables change of equilibrium state through transfer of mechanical energy. Consider the gas of the previous example in equilibrium state (P, V).



The rigid upper wall of the cylinder is now replaced with an adiabatic movable piston. On pushing the piston down, the pressure increases and the volume decreases. At a particular position of the piston, after sufficient time for pressure to become the same everywhere, the gas acquires a new equilibrium state (P′, V′). If the piston is not allowed to move any more, the gas will continue to be in this new equilibrium state (P′, V′).

A diathermic boundary enables change of equilibrium state through transfer of heat energy. Let us consider another closed system – a gas in a cylinder with a diathermic bottom, kept on an insulating platform. The gas is in equilibrium state (P, V). If we keep the cylinder on a hot plate, heat flows into the cylinder through the bottom. The gas continues to occupy the same volume, but the pressure increases. When pressure has increased to, say, P″, the cylinder is removed from the hot plate and kept again on an insulating platform. Now the gas continues in the new equilibrium state (P″, V) as no more heat is supplied.



Example

Which of the following are true?

a) Equilibrium state of a closed system can change but not of an isolated system.

b) Equilibrium state of an open system can change but not of a closed system.

c) Equilibrium state of an open system can change but not of an isolated system.

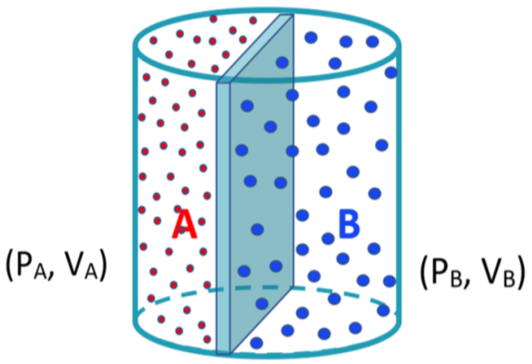
d) Equilibrium state of an isolated system can change but not of an open system.

Answer: a), c)

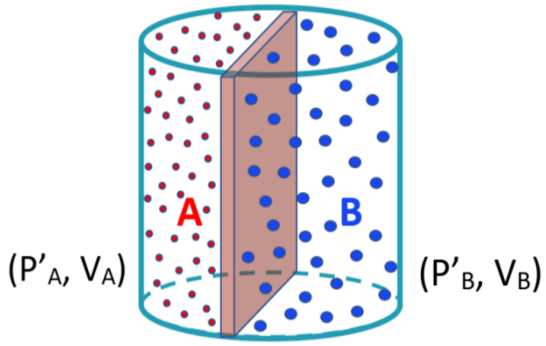
Heat Exchange between Systems

Two systems in diathermic contact are said to be in thermal equilibrium if there is no net heat exchange between the systems. Two systems can exchange heat if they are in contact through a diathermic wall. When two systems exchange heat, initially there is a change in some property of both the systems. Eventually, the change in property stops and we infer that there is no more net heat exchange between the systems. At this stage, the systems are said to be in thermal or thermodynamic equilibrium with each other.

Consider two gases A and B enclosed in a container with adiabatic walls and an adiabatic partition between them. Let pressure and volume parameters are (P_A, V_A) for gas A and (P_B, V_B) for gas B. The gas A will continue in the same equilibrium state (P_A, V_A) because rigid adiabatic walls do not permit transfer of any energy to it. The equilibrium state of gas B also continues to be (P_B, V_B) for the same reason.



Systems A and B separated by adiabatic partition, the equilibrium states do not change.



Now if the adiabatic partition is replaced with a diathermic partition, the energy flows as heat and the states of gas A as well gas B start changing spontaneously.

System A and B separated by diathermal partition. The macroscopic variables become constant at thermal equilibrium

It is observed that the pressure stops changing when both systems attain equilibrium states, say (P'_A, V_A) and (P'_B, V_B) respectively. This indicates heat exchange between them must have stopped despite thermal contact

Point to be noted

In thermal equilibrium, systems do not exchange any net heat even though they are in diathermic contact and capable of exchanging heat. The heat flowing in and out of the system becomes the same.

Thermal Equilibrium between Two System & Concept of Temperature

We have learnt in Calorimetry that the temperatures of the two systems in thermal equilibrium with each other are equal. We now learn how temperature emerges as a fundamental concept from the thermal equilibrium between systems.

Thermal equilibrium indicates ‘all heat is of the same kind’.

Let’s understand how.Suppose two persons A and B have 10 kg and 20 kg of grain respectively. They mutually exchange 2 kg of grain with each other. After the exchange, consider two different possibilities as follows:

a) After the mutual exchange, A is found to have 8 kg of one type of grain, say X and 2 kg of another type of grain, say Y. B is found with 18 kg of grain Y and 2 kg of grain X.

   We would conclude that A and B had different types of grains (X & Y) initially. After the exchange, both A and B have both X and Y types of grains in different quantities.

b) After the mutual exchange, A still has 10 kg grain of one type and B also has 20 kg grain of the same type.

We would then conclude that A and B exchanged the same type of grains and they had the same type of grains initially also.

Let us apply this understanding to thermodynamics.

During the process of reaching thermal equilibrium, heat which is energy in transit is mutually exchanged between two systems A and B, the net transfer being from the hotter to the colder. But on reaching thermal equilibrium, there is no net transfer of energy. That means, at thermal equilibrium the quantity of energy that goes from A to B is balanced by the same amount of energy received by A from B. This is possible only if energies given out by both systems are similar in nature. Thus, the energy given out by A and that given out by B, both are heat (energy in transit) and the same kind of heat.

'All heat is of the same kind' was famously said by Maxwell!

Temperature is a fundamental property of all materials.Heat given out by every material is of the same kind - this is true even if the composition of systems A and B is different, their atomic masses are different, the energy per unit mass is different due to different specific heat capacities. This implies that heat transfer between them is governed by a property common to both A and B . A property that is more fundamental than even the nature of their atoms. This fundamental property is temperature and is the subject of the zeroth law of thermodynamics.

Example

Thermal equilibrium between a piece of ice and glycerine is possible because

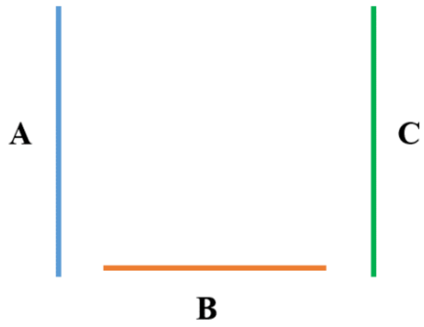
a) The compositions of glycerine and ice are same
b) The masses of glycerine and ice must have been same
c) The nature of energy exchanged by both ice and glycerine is the same
d) The color of ice and glycerol are same

Answer: c)

Zeroth Law of Thermodynamics

Statement: "If system A is in thermal equilibrium with system B and system B is in thermal equilibrium with system C, then system C will be in thermal equilibrium with system A."

The law is a statement of common observation and may seem trivial, but it should not be taken as obvious.



For example, as shown in the figure, if A is perpendicular to B and B is perpendicular to C, it is not necessary that C is perpendicular to A!

Let us consider three closed systems A, B and C. Let A and C be separated by an adiabatic wall, while each is in contact with B via a conducting wall (Fig a).

Some physical properties (macroscopic variables) of the three systems change until A and C individually reach thermal equilibrium with B.

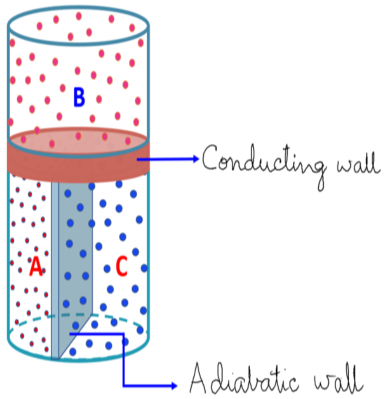


Fig (a)

Next, the adiabatic wall between A and C is replaced with a conducting wall and B is insulated from A and C by an adiabatic wall (Fig b). No further change is observed in properties of A and C i.e. they are found to be in thermal equilibrium with each other. This observation is stated in the form of the Zeroth law of thermodynamics.

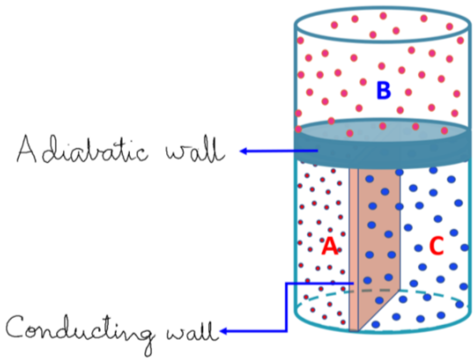
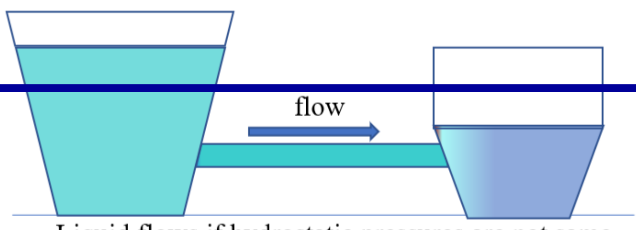


Fig (b)

"Equality of temperature is a necessary and sufficient condition for thermal equilibrium between systems."

The law implies the existence of a criterion for thermal equilibrium - whenever two systems A & B are in thermal equilibrium, there exists a property called temperature which is the same for both systems. Now if a third system C is also in thermal equilibrium with system B, we can be confident that all the three systems A, B and C have the same value of this property called temperature.

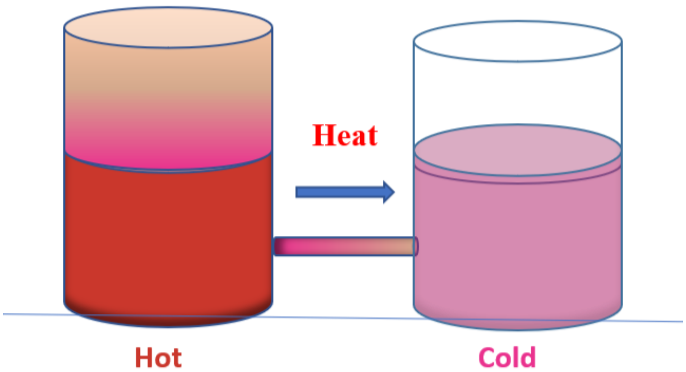
In the case of two interconnected non-reactive liquids, pressure is the physical property enabling us to anticipate how long the



liquid flow happens and in which direction, regardless of the composition and size of the liquids in contact. Liquid flow stops when pressures become the same in the two vessels.

Similarly, temperature is the property which enables us to anticipate how long the heat will flow in a preferred direction between two systems regardless of the size and composition of the systems. Heat flow seems to stop when the temperatures become equal.

The heat flow becomes heat exchange, which means the heat flowing out of the system equals the heat flowing into the system, after all why would the equilibrium flow change if there is even a slight change in temperature of one or both systems.



Heat flows if the temperatures are not equal

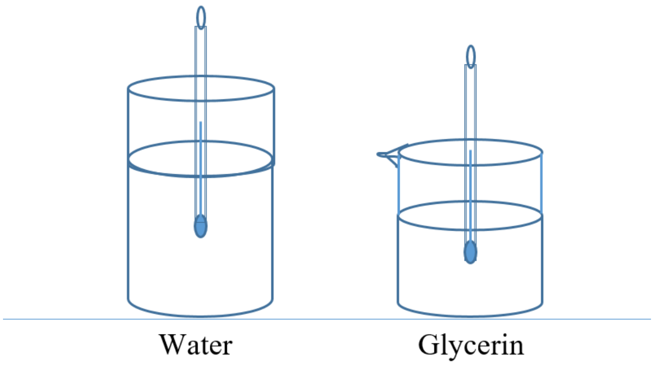
Zeroth Law of thermodynamics is an afterthought!

Long after the first and second laws of thermodynamics were firmly established, it was realized that such a law was essential to complete the logical structure of thermodynamics. It was so fundamental and provided such a basis for other laws that it had to precede them – hence the name 'Zeroth law'!

Zeroth Law & Temperature Measurement

The Zeroth law forms the fundamental basis of existence of a device that can measure temperature i.e. a thermometer.

A thermometer is just a special case of system B that we discussed in the Zeroth law of thermodynamics. It is a system with a thermometric property that can change when put in thermal contact with another system. Thus, when system B i.e. the thermometer, is put in thermal contact with A, say, water in a glass, the length of mercury thread in the thermometer changes initially but stops changing eventually. At this stage, the thermometer and water are in thermal equilibrium and have the same temperature. Now if the thermometer is put in thermal contact with system C, say glycerine in a beaker and the length of mercury thread is found to be at the same level, we can report that water in glass and glycerine in beaker are at same



temperature. We state that the temperature of water and glycerine is the same without the need of putting them in direct contact with each other. The Zeroth law of thermodynamics empowers us with this capability.

However, the Zeroth law of thermodynamics is silent about the numerical value to be assigned to a temperature i.e. how to construct a temperature scale. This is the subject matter of the second law of thermodynamics.

Check Your Understanding

Example

A beaker of hot water and a beaker of cold water are placed on a table in a room. After a very long time, which beaker is at a higher temperature?

Solution: "After a very long time" implies that the beakers are allowed to reach thermal equilibrium with the room. Since they are both in thermal equilibrium with the room, they must be in thermal equilibrium with each other. They are at the same temperature, at room temperature.

Daily Life Observations:

- We find premature or sick newborn babies placed in special incubators in neonatal intensive care units of hospitals. They have very little covering and to an onlooker, may not appear to be warm enough. But everything inside the incubator is in thermal equilibrium. The air, the cot, the baby - all are at the same temperature. The ambient temperature is just high enough to keep the baby safe and comfortable.

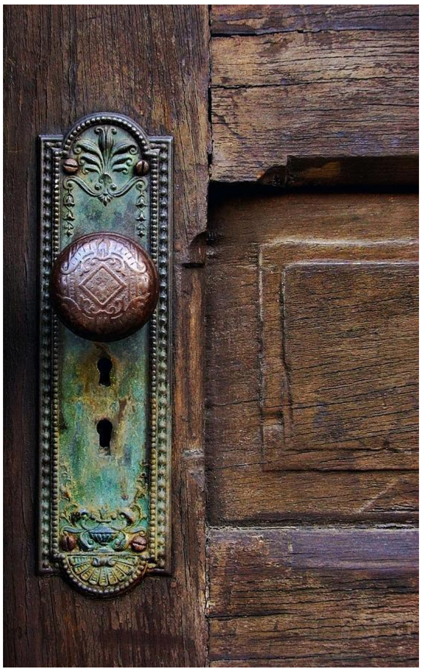
Credit : Zerbey at the English language Wikipedia

https://commons.wikimedia.org/wiki/File:Human_Infant_in_Incubator.jpg

- **Consider taking your own body temperature. You place the clinical thermometer very gently under your tongue.** Heat flows from you through a thin wall of glass into a reservoir of liquid, which is usually mercury.Thermal expansion causes the mercury to be pushed up a capillary tube with a graduated scale.

  It is the temperature of mercury, and its ensuing uniform thermal expansion that is used to measure the temperature under your tongue. At no point, does the poisonous mercury actually come in direct contact with your mouth.

- We often associate the concept of temperature with how hot or cold an object feels when we touch it. For example, on a cold winter morning, the metal handles of a door or metal bench in the garden feels colder than the door or a wooden bench even though both are at the same temperature.



https://images.fineartamerica.com/images/artworkimages/mediumlarge/1/old-door-knob-joanne-coyle.jpg

Credit: Agnes Monkelbaan

https://commons.wikimedia.org/wiki/File:Bank_in_Engelse_tuin._Locatie,_Tuinen_Mien_Ruys_in_Dedemsvaart.jpg

It is a misconception that our sensations of warmth and cold are directly related to temperature or temperature-difference between our body and the object. They are related to heat. **Heat is the flow of thermal energy**. When heat flows into our body we perceive it as warmth and when heat flows out of our body we feel it as cold. Higher the rate of heat flow warmer/colder it feels. Metal being a good thermal conductor allows heat to flow easily from our hands and hence feels colder. On the other hand, a wooden bench being an insulator, does not allow heat to flow from our body so easily, hence feels warmer.

- **Understanding of heat exchange is crucial for engineers dealing with insulation, enhancement or temperature control.**

  Insulation requires minimum heat transfer across a finite temperature difference between a system and its surroundings. This is achieved using very poor heat conductors in case of conduction mode. A thermos flask on the other hand achieves it through near vacuum in the annular space between its walls as this minimizes the radiation mode of heat transfer.

Enhancement requires promotion of heat transfer across a finite temperature difference. Convection is one easy way of doing this. Simplest example is blowing hot milk to cool it. Heat exchangers are used in big power plants for this purpose.

Read about the latest in technology here: Cooling system works without electricity

https://www.sciencedaily.com/releases/2017/09/170905145530.htm

Temperature control requires the temperature of a region to be maintained close to a specific value and it may involve both insulation and enhancement at different stages. Electronic devices use phase change material to maintain their operation temperature. Heat is rejected to phase change material when the devices are switched on and phase change material is allowed to cool when the device is switched off.

A **thermostat** is another common device which helps maintain the temperature of a system near a desired set-point. A thermostat exerts control by switching heating or cooling devices on or off, or by regulating the flow of a heat transfer fluid as needed, to maintain the correct temperature. They are used in building heating, central heating, air conditioners, as well as kitchen equipment including ovens and refrigerators and medical and scientific incubators.
Read about the latest in technology here: Smart clothing of the future will automatically adjust itself according to the wearer's actual needs

https://www.sciencedaily.com/releases/2016/03/160309083254.htm

- **Thermoregulation of our human body** is another example of temperature control. It is achieved through increased or reduced blood supply to localized regions coupled with mechanisms like sweating. Messing up of this mechanism results in fever or hypothermia.

Summary

- **Thermodynamics** is the study of relation between heat and temperature and inter-conversion of heat and other forms of energy. It is a macroscopic science.
- **Thermodynamic system:** Part of the universe that is the center of attention, under consideration.
    - **Surroundings**: Everything in the environment of the system, which has direct bearing on the thermal behavior of the system
    - **Boundary**: surface separating the system from surroundings
- **Open system**: system that can exchange matter and energy with the surroundings
    - **Closed system**: system that can only exchange energy with the surroundings
    - **Isolated system**: system that can exchange neither energy nor matter with the surroundings

- **Adiabatic wall**: boundary that prevents heat exchange
- **Diathermic wall**: boundary that allows heat exchange
- A thermodynamic system is in **Equilibrium state** if all the macroscopic variables that describe the system do not change in time and in space.
- Thermodynamics can describe a system only if it is in equilibrium, otherwise not
- Thermal interaction with the surroundings can change the given equilibrium state of a thermodynamic system.
- The nature of thermal interaction is determined by the nature of the boundary and surroundings.
- Two systems are in thermal equilibrium when there is no change in macroscopic variables of each. At thermal equilibrium, there is no net heat exchange between them.
- Temperature is a fundamental property of every system which directs heat flow between any two systems.
- Zeroth law of thermodynamics: If system A is in thermal equilibrium with system B and system B is in thermal equilibrium with system C, then system C will be in thermal equilibrium with system A.
- Consequence of Zeroth law: B acts like a thermometer, and A, B, and C are all at the same "temperature".