

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ



Applied Thermodynamics

Week_01

Instructor: Mr. Adnan Qamar

Mechanical Engineering Department

Course Outline

ME 111 Thermodynamics-I

Thermodynamics, system, continuum, properties, state, thermodynamic equilibrium, state postulate and its conclusions, process, cycle, zeroth law of thermodynamics, forms of energy, energy transfer by heat, energy transfer by work, moving boundary work and other forms of work, properties of pure substances, phase change processes of pure substance, critical and triple point, property diagrams for phase change processes, use of property tables, ideal gas equation, specific heats, Joule's law, internal energy, enthalpy and specific heats of perfect gases, liquids and solids, first law of thermodynamics, first law of thermodynamics applied to non – flow processes, continuity equation, first law of thermodynamics applied to flow processes, steady flow energy equation and steady flow engineering devices, uniform state and uniform flow processes,

Course Outline

ME 111 Thermodynamics-I

second law of thermodynamics, statements, corollaries, thermodynamic temperature scale, reversible and irreversible processes, entropy and its application to non-flow and flow processes, temperature-entropy and enthalpy-entropy diagrams, generation of steam through boilers, classification, configurations and applications of boilers, boiler efficiencies, energy analysis of boilers, boiler Draughts, concept of steam condenser and its types, thermodynamic cycles, Carnot cycle, gas power cycles, vapor power cycles, vapor compression cycle

Course Outline

Recommended Books:

1. Thermodynamics, An Engineering Approach, Y. A. Cengel and M. A. Boles
2. Applied Thermodynamics for Engineering Technologists, T.D. Eastop, A. McConkey
3. Basic Engineering Thermodynamic, Rayner Joel
4. Fundamentals of Engineering Thermodynamics, Moran, Shapiro

Prerequisite:

NA

Introduction & Basic Concepts of Thermodynamics

Introduction:

The most of general sense of **thermodynamics is the study of energy and its relationship to the properties of matter**. All activities in nature involve some interaction between energy and matter. Thermodynamics is a science that governs the following:

- Energy and its transformation
- Feasibility of a process involving transformation of energy
- Feasibility of a process involving transfer of energy
- Equilibrium processes

More specifically, thermodynamics deals with energy conversion, energy exchange and the direction of exchange.

Introduction & Basic Concepts of Thermodynamics

Areas of Application of Thermodynamics:

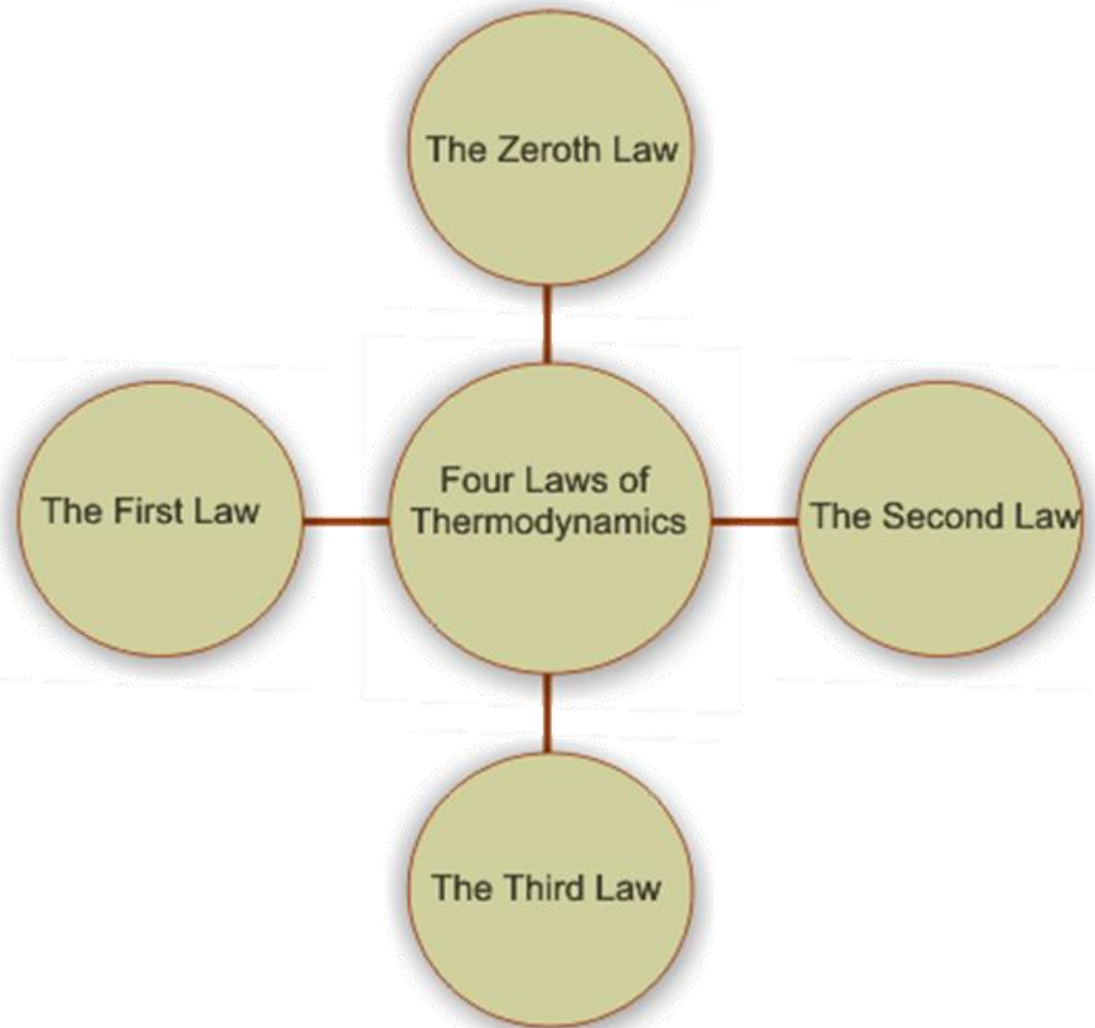
All natural processes are governed by the principles of thermodynamics. However, the following engineering devices are typically designed based on the principles of thermodynamics.

Automotive engines, Turbines, Compressors, Pumps, Fossil and Nuclear Power Plants, Propulsion systems for the Aircrafts, Separation and Liquefaction Plant, Refrigeration, Air-conditioning and Heating Devices.

The principles of thermodynamics are summarized in the form of a set of axioms. These axioms are known as four thermodynamic laws:

Introduction & Basic Concepts of Thermodynamics

The zeroth law, the first law, the second law and the third law:



Introduction & Basic Concepts of Thermodynamics

- **The Zeroth Law** deals with thermal equilibrium and provides a means for measuring temperatures.
- **The First Law** deals with the conservation of energy and introduces the concept of internal energy.
- **The Second Law** of thermodynamics provides with the guidelines on the conversion of internal energy of matter into work. It also introduces the concept of entropy.
- **The Third Law** of thermodynamics defines the absolute zero of entropy. The entropy of a pure crystalline substance at absolute zero temperature is zero.

Introduction & Basic Concepts of Thermodynamics

Different Approaches in the Study of Thermodynamics:

Thermodynamics can be studied through two different approaches:

- (a) **Macroscopic Approach and**
- (b) **Microscopic Approach**

Introduction & Basic Concepts of Thermodynamics

Macroscopic Approach:

Consider a certain amount of gas in a cylindrical container. The volume (V) can be measured by measuring the diameter and the height of the cylinder. The pressure (P) of the gas can be measured by a pressure gauge. The temperature (T) of the gas can be measured using a thermometer. The state of the gas can be specified by the measured P , V and T . The values of these variables are space averaged characteristics of the properties of the gas under consideration. In classical thermodynamics, we often use this macroscopic approach.

The macroscopic approach has the following features.

- The structure of the matter is not considered.
- A few variables are used to describe the state of the matter under consideration.
- The values of these variables are measurable following the available techniques of experimental physics.

Introduction & Basic Concepts of Thermodynamics

Microscopic Approach:

On the other hand, the gas can be considered as assemblage of a large number of particles each of which moves randomly with independent velocity. The state of each particle can be specified in terms of position coordinates (x_i, y_i, z_i) and the momentum components (p_{xi}, p_{yi}, p_{zi}) . If we consider a gas occupying a volume of 1 cm^3 at ambient temperature and pressure, the number of particles present in it is of the order of 10^{20} . The same number of position coordinates and momentum components are needed to specify the state of the gas. **The microscopic approach can be summarized as:**

- A knowledge of the molecular structure of matter under consideration is essential.
- A large number of variables are needed for a complete specification of the state of the matter.

Introduction & Basic Concepts of Thermodynamics

SI Units

SI is the abbreviation of System International Unites. The SI units for mass, length, time and force are kilogram, meter, second and newton respectively. The unit of length is meter, m, defined as 1, 650, 763.73 wavelengths in vacuum of the radiation corresponding to the orange-red line of the spectrum of Krypton-86. The unit of time is second, s. The second is defined as the duration of 9, 192, 631, 770 cycles of the radiation associated with a specified transition of the Cesium 133 atom. The unit of mass is kilogram, kg. It is equal to the mass of a particular cylinder of platinum-iridium alloy kept at the International Bureau of Weights and Measures.

Introduction & Basic Concepts of Thermodynamics

SI Units:

The amount of substance can also be expressed in terms of the mole (mol). One kilomole of a substance is the amount of that substance in kilograms numerically equal to its molecular weight. The number of kilomoles of a substance, n , is obtained by dividing the mass (m) in kilograms by the molecular weight (M), in kg/ kmol.

$$n = m/M$$

The unit for temperature is Kelvin, K . One K is the fraction $1/273.16$ of the thermodynamic temperature of the triple point of water. Quite often the Celsius, $^{\circ}\text{C}$, is used to express the temperature of a substance.

$$^{\circ}\text{C} = \text{K} - 273.16$$

The SI unit of force, called the newton, N is a secondary unit. The, N, is the force required to accelerate a mass of 1 kilogram at the rate of 1 meter per (second)².

$$1 \text{ N} = (1\text{kg}) (1\text{m/s}^2) = 1\text{kg m/s}^2$$

Introduction & Basic Concepts of Thermodynamics

SI Units:

The smaller or bigger quantities are expressed using the following prefixes

Factor	Prefix	Symbol	Factor	Prefix	Symbol
10^{12}	tera	<i>T</i>	10^{-2}	centi	<i>c</i>
10^9	giga	<i>G</i>	10^{-3}	milli	<i>m</i>
10^6	mega	<i>M</i>	10^{-6}	micro	μ
10^3	kilo	<i>k</i>	10^{-9}	nano	<i>n</i>
10^2	hecto	<i>h</i>	10^{-12}	pico	<i>p</i>

Introduction & Basic Concepts of Thermodynamics

Pressure:

Pressure is the normal force exerted by a system against unit area of the boundary surface.

$$\lim_{\delta A \rightarrow 0} \frac{F_n}{\delta A}$$

where δA approaches zero.

The unit for pressure in SI is Pascal, Pa;

$$1 \text{ Pa} = 1 \text{ N/m}^2$$

Two other units are widely used;

$$1 \text{ bar} = 10^5 \text{ Pa} = 100 \text{ kPa} = 0.1 \text{ MPa}$$

and the standard atmosphere, where

$$1 \text{ atm} = 101.325 \text{ kPa} = 1.01325 \text{ bar} = \text{pressure exerted by a column of 760 mm of Hg}$$

Introduction & Basic Concepts of Thermodynamics

Energy:

Energy is the capacity to exert a force through a distance. In SI, the unit of energy is Newton-meter, N m or Joule, J.

Power:

The rate of energy transfer or storage is called power. The unit of power is watt, W.

$$\underline{1 \text{ W} = 1 \text{ J/s} = 1 \text{ N m/s and } 1 \text{ kW} = 1000 \text{ W.}}$$

Apart from these, the following units are used for various parameters of interest

Frequency, Hertz = Hz = s⁻¹ ; Electric current, Ampere = A

Electric charge, Coulomb, C = As ; Electric potential, Volt = V = W/A

Magnetic flux, Weber, Wb = Vs ; Magnetic flux density, Tesla, T = Wb/m²

Introduction & Basic Concepts of Thermodynamics

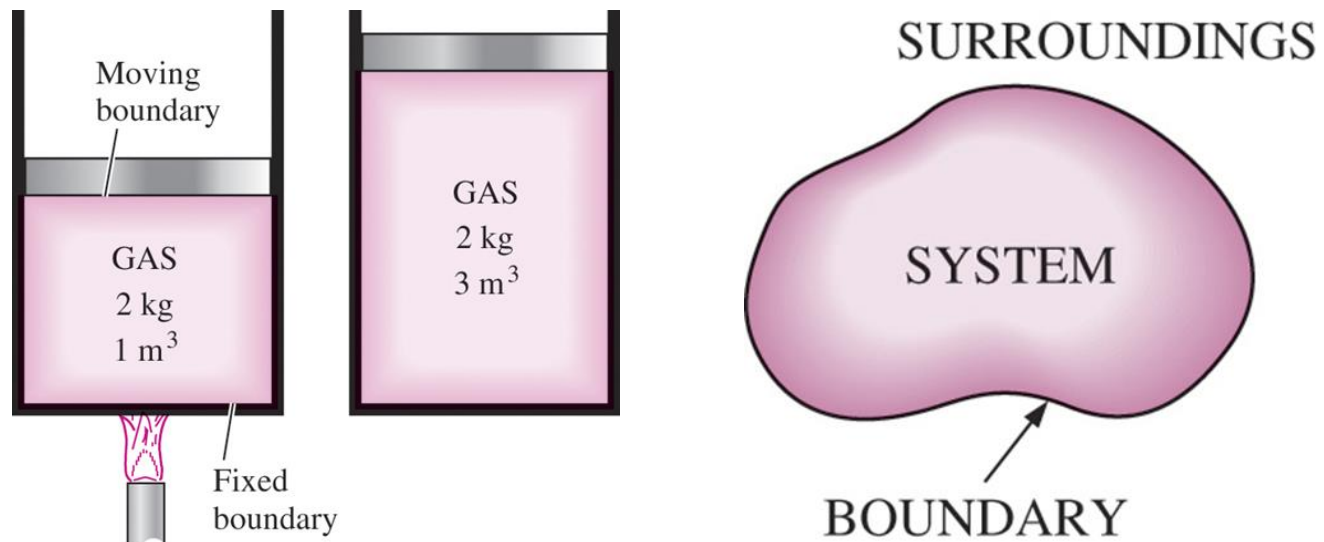
System:

A thermodynamic system is defined as a definite quantity of matter or a region in space upon which attention is focussed in the analysis of a problem. We may want to study a quantity of matter contained within a closed rigid walled chamber, or we may want to consider something such as a gas pipeline through which the matter flows. The composition of the matter inside the system may be fixed or may change through chemical and nuclear reactions. A system may be arbitrarily defined. It becomes important when exchange of energy between the system and everything else outside the system is considered. The judgment on the energetics of this exchange is very important.

Introduction & Basic Concepts of Thermodynamics

Surroundings:

Everything external to the system is surroundings. The system is distinguished from its surroundings by a specified boundary which may be at rest or in motion. The interactions between a system and its surroundings, which take place across the boundary, play an important role in thermodynamics. A system and its surroundings together comprise a universe.



Introduction & Basic Concepts of Thermodynamics

Types of systems:

Two types of systems can be distinguished. These are referred to, respectively, as closed systems and open systems or control volumes. A closed system or a control mass refers to a fixed quantity of matter, whereas a control volume is a region in space through which mass may flow. A special type of closed system that does not interact with its surroundings is called an Isolated system .

Two types of exchange can occur between the system and its surroundings:

- energy exchange (heat or work) and
- exchange of matter (movement of molecules across the boundary of the system and surroundings).

Introduction & Basic Concepts of Thermodynamics

Types of systems:

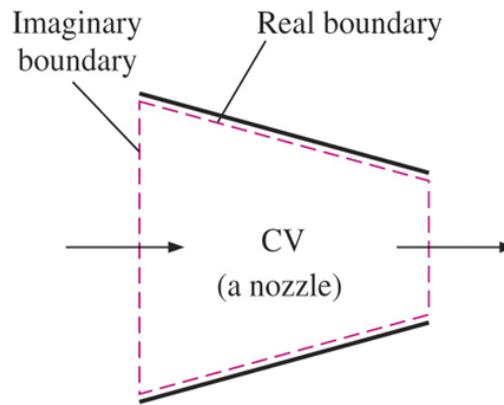
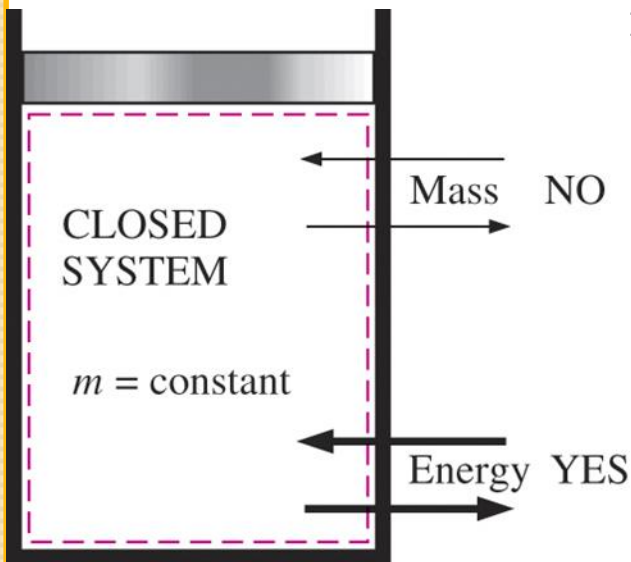
Based on the types of exchange, one can define

- **isolated systems:** no exchange of matter and energy
- **closed systems:** no exchange of matter but some exchange of energy
- **open systems:** exchange of both matter and energy

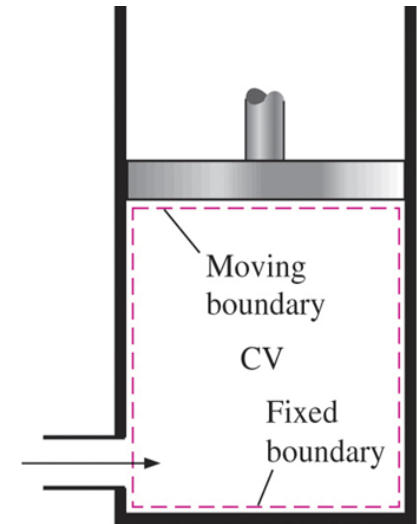
If the boundary does not allow heat (energy) exchange to take place it is called adiabatic boundary otherwise it is diathermal boundary.

Introduction & Basic Concepts of Thermodynamics

Types of systems:



(a) A control volume with real and imaginary boundaries



(b) A control volume with fixed and moving boundaries

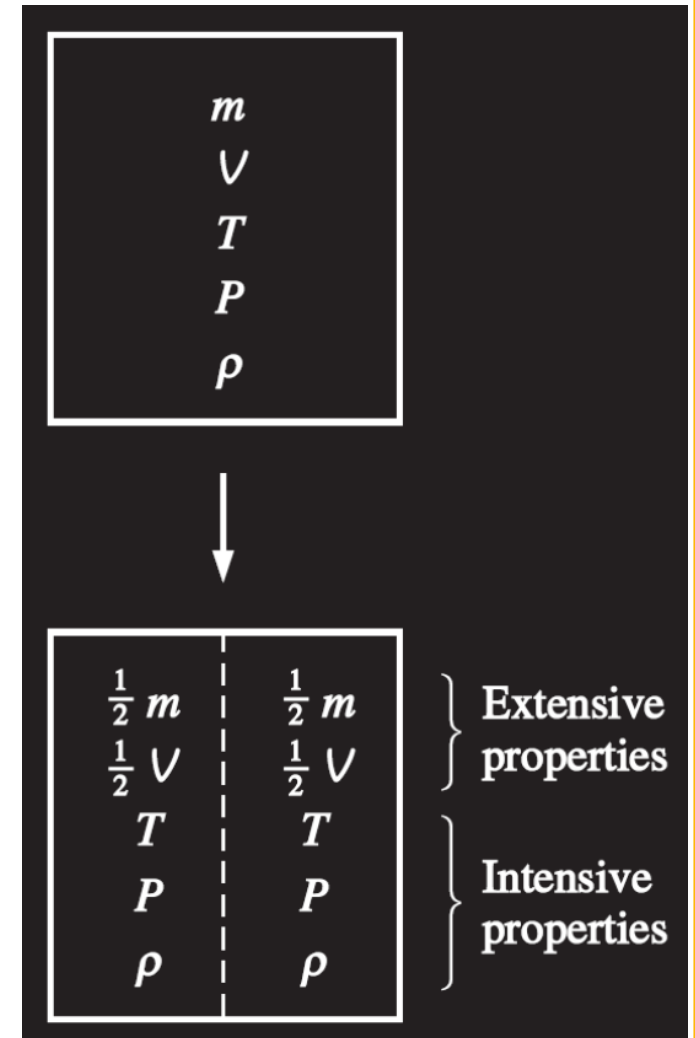
Introduction & Basic Concepts of Thermodynamics

Property: Any characteristic of a system. Some familiar properties are pressure P , temperature T , volume V , and mass m . Properties are considered to be either intensive or extensive.

Intensive properties: Those that are independent of the mass of a system, such as temperature, pressure, and density.

Extensive properties: Those whose values depend on the size—or extent—of the system.

Specific properties: Extensive properties per unit mass.



Criterion to differentiate intensive and extensive properties.

Introduction & Basic Concepts of Thermodynamics

The ratio of the extensive property to the mass is called the specific value of that property .

specific volume, $v = V/m = 1/\rho$ (ρ is the density)

specific internal energy, $u = U/m$

Similarly, the molar properties are defined as the ratios of the properties to the mole number (N) of the substance

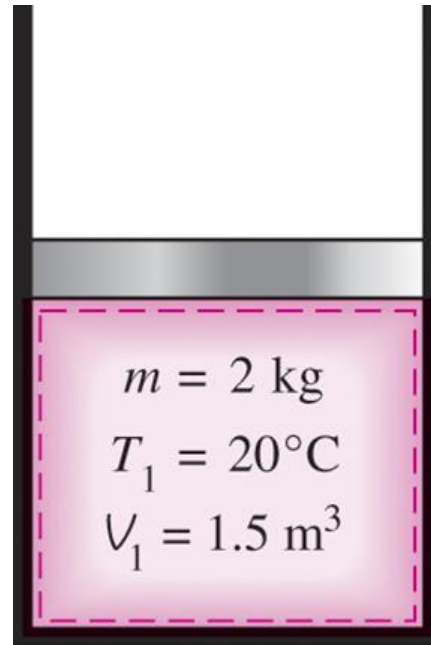
Molar volume $=v = V/N$

Molar internal energy $= u = U/N$

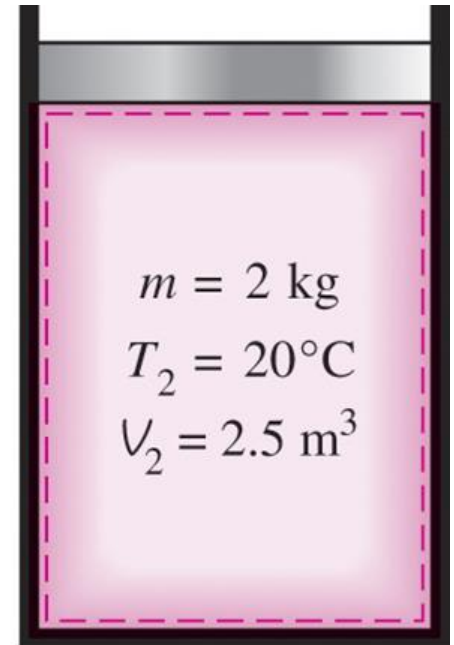
Introduction & Basic Concepts of Thermodynamics

State:

It is the condition of a system as defined by the values of all its properties. It gives a complete description of the system. Any operation in which one or more properties of a system change is called a change of state.



(a) State 1



(b) State 2

A system at two different states.

Introduction & Basic Concepts of Thermodynamics

The State Postulate: The number of properties required to fix the state of a system is given by the **state postulate**:

✓The state of a simple compressible system is completely specified by two independent, intensive properties.

Simple compressible system: If a system involves no electrical, magnetic, gravitational, motion, and surface tension effects.



The state of nitrogen is fixed by two independent, intensive properties.

Introduction & Basic Concepts of Thermodynamics

Equilibrium State:

- A system is said to be in an equilibrium state if its properties will not change without some perceivable effect in the surroundings.
- Equilibrium generally requires all properties to be uniform throughout the system.
- There are mechanical, thermal, phase, and chemical equilibrium.

Nature has a preferred way of directing changes.eg:

- water flows from a higher to a lower level
- Electricity flows from a higher potential to a lower one
- Heat flows from a body at higher temperature to the one at a lower temperature
- Momentum transfer occurs from a point of higher pressure to a lower one.
- Mass transfer occurs from higher concentration to a lower one

Introduction & Basic Concepts of Thermodynamics

Types of Equilibrium

Between the system and surroundings, if there is no difference in

- Pressure → Mechanical equilibrium
- Potential → Electrical equilibrium
- Concentration of species → Species equilibrium
- Temperature → Thermal equilibrium

No interactions between them occur. They are said to be in equilibrium.

Thermodynamic equilibrium implies all those together. A system in thermodynamic equilibrium does not deliver anything.

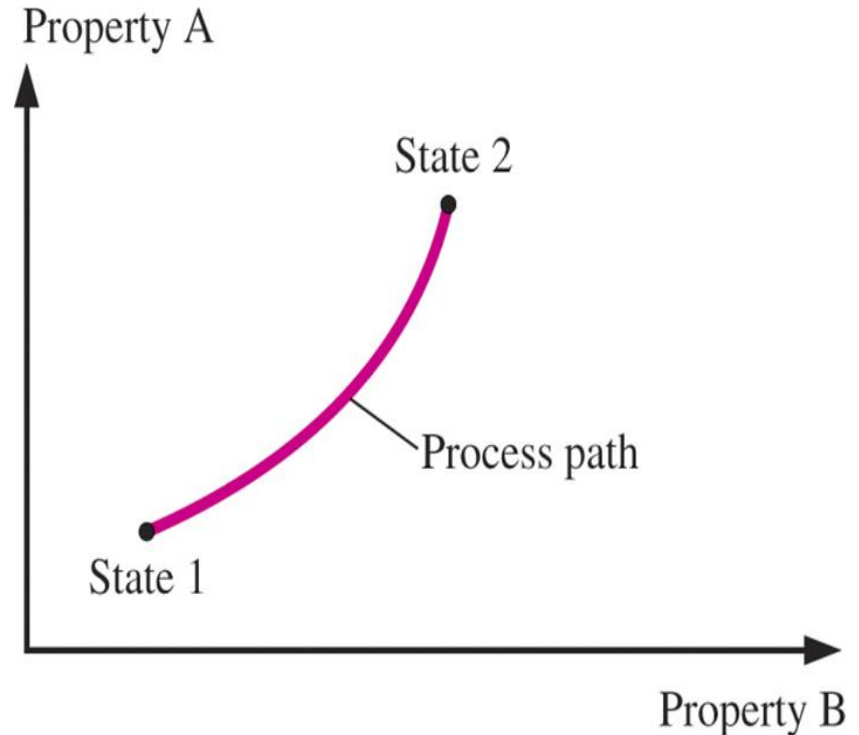
Introduction & Basic Concepts of Thermodynamics

PROCESSES AND CYCLES

Process: Any change that a system undergoes from one equilibrium state to another.

Path: The series of states through which a system passes during a process.

To describe a process completely, one should specify the initial and final states, as well as the path it follows, and the interactions with the surroundings.

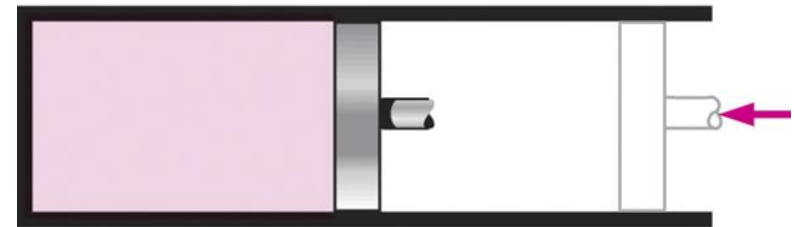


Introduction & Basic Concepts of Thermodynamics

Quasi-equilibrium process: When a process proceeds in such a manner that the system remains infinitesimally close to an equilibrium state at all times.



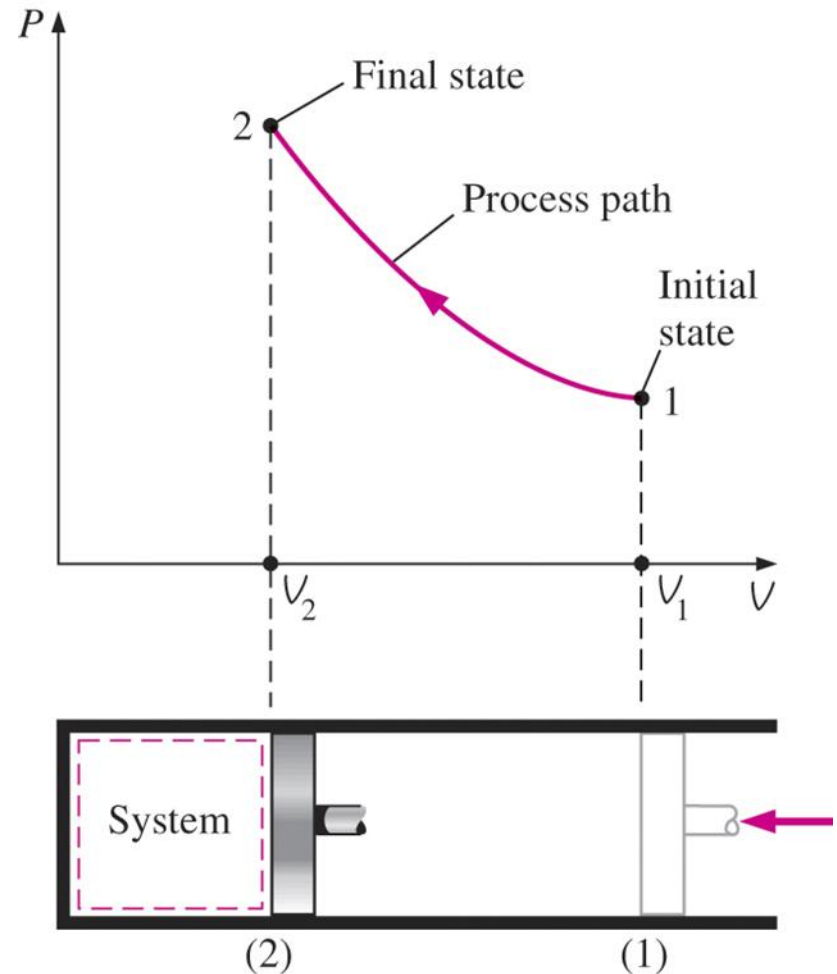
(a) Slow compression
(quasi-equilibrium)



(b) Very fast compression
(nonquasi-equilibrium)

Introduction & Basic Concepts of Thermodynamics

- Process diagrams plotted by employing thermodynamic properties as coordinates are very useful in visualizing the processes.
- Some common properties that are used as coordinates are temperature T , pressure P , and volume V (or specific volume v).
- The prefix iso- is often used to designate a process for which a particular property remains constant.



The P - V diagram of a compression process.

Introduction & Basic Concepts of Thermodynamics

Types of Processes

- As a matter of rule we allow one of the properties to remain a constant during a process.
- Construe as many processes as we can (with a different property kept constant during each of them)
- Complete the cycle by regaining the initial state

(1) Isothermal (T)

(2) Isobaric (p)

(3) Isochoric (v)

(4) Isentropic (s)

(5) Isenthalpic (h)

(6) Isosteric (concentration)

(7) Adiabatic (no heat addition or removal)

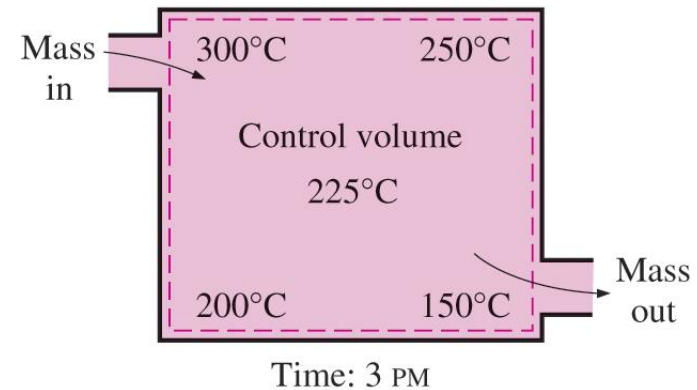
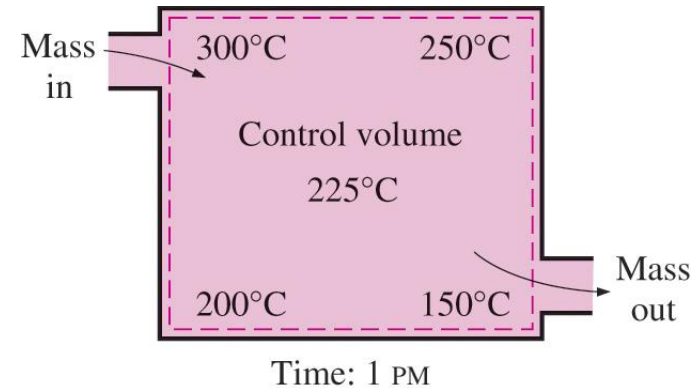
Cycle: A process during which the initial and final states are identical.

Introduction & Basic Concepts of Thermodynamics

The Steady-Flow Process:

➤ The term **steady** implies **no change with time**. The opposite of steady is **unsteady, or transient**.

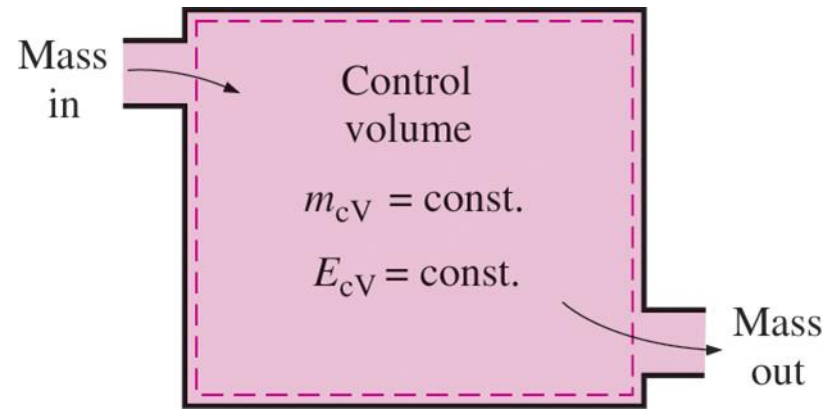
➤ A large number of engineering devices operate for long periods of time under the same conditions, and they are classified as **steady-flow devices**.



During a steady-flow process, fluid properties within the control volume may change with position but not with time.

Introduction & Basic Concepts of Thermodynamics

➤ **Steady-flow process:** A process during which a fluid flows through a control volume steadily.



Under steady-flow conditions, the mass and energy contents of a control volume remain constant.

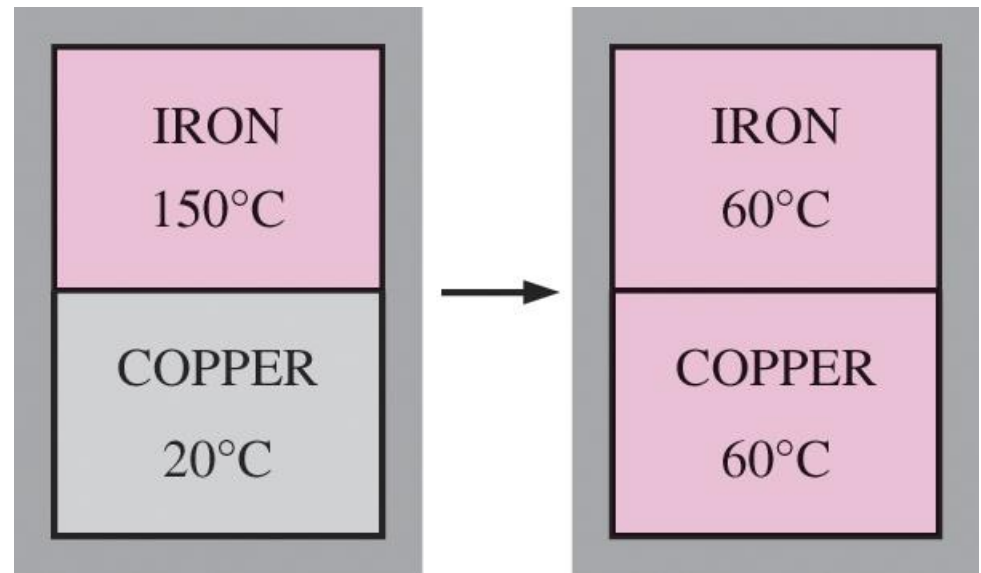
➤ Steady-flow conditions can be closely approximated by devices that are intended for continuous operation such as **turbines, pumps, boilers, condensers, and heat exchangers or power plants or refrigeration systems.**

Introduction & Basic Concepts of Thermodynamics

TEMPERATURE AND THE ZEROETH LAW OF THERMODYNAMICS

- **The zeroth law of thermodynamics:** If two bodies are in thermal equilibrium with a third body, they are also in thermal equilibrium with each other.
- By replacing the third body with a thermometer, the zeroth law can be restated as **two bodies are in thermal equilibrium if both have the same temperature reading even if they are not in contact.**

Two bodies reaching thermal equilibrium after being brought into contact in an isolated enclosure.



Introduction & Basic Concepts of Thermodynamics

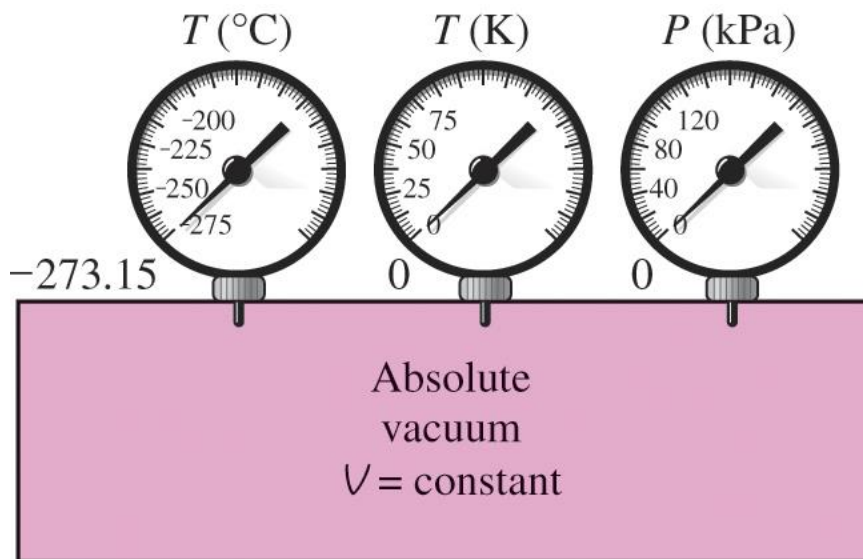
Temperature Scales:

- All temperature scales are based on some easily reproducible states such as the freezing and boiling points of water: the *ice point* and the *steam point*.
- **Ice point:** A mixture of ice and water that is in equilibrium with air saturated with vapor at 1 atm pressure (0°C or 32°F).
- **Steam point:** A mixture of liquid water and water vapor (with no air) in equilibrium at 1 atm pressure (100°C or 212°F).
- **Celsius scale:** in SI unit system
- **Fahrenheit scale:** in English unit system
- **Thermodynamic temperature scale:** A temperature scale that is independent of the properties of any substance.
- **Kelvin scale (SI) Rankine scale (E)**

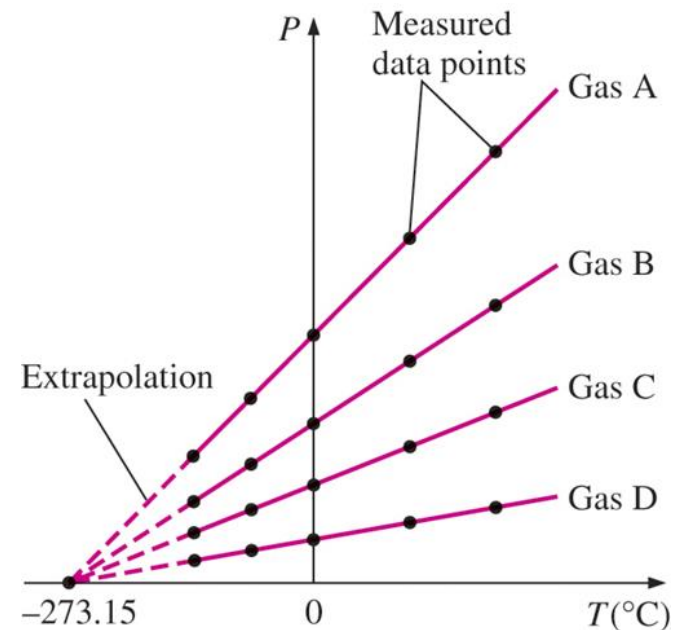
Introduction & Basic Concepts of Thermodynamics

Temperature Scales:

- A temperature scale nearly identical to the Kelvin scale is the **ideal-gas temperature scale**. The temperatures on this scale are measured using a **constant-volume gas thermometer**.



A constant-volume gas thermometer would read -273.15°C at absolute zero pressure.



P versus T plots of the experimental data obtained from a constant-volume gas thermometer using four different gases at different (but low) pressures.

Introduction & Basic Concepts of Thermodynamics

$$T(\text{K}) = T(^{\circ}\text{C}) + 273.15$$

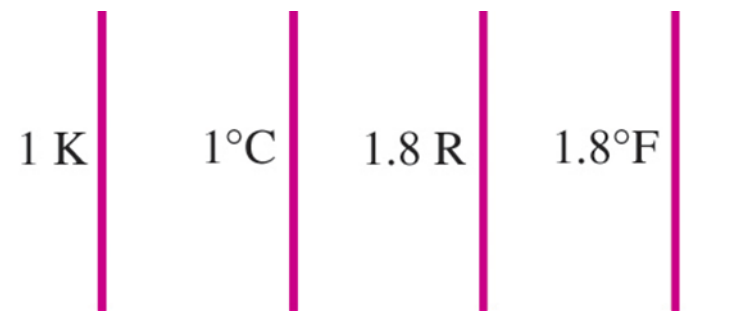
$$T(\text{R}) = T(^{\circ}\text{F}) + 459.67$$

$$T(\text{R}) = 1.8T(\text{K})$$

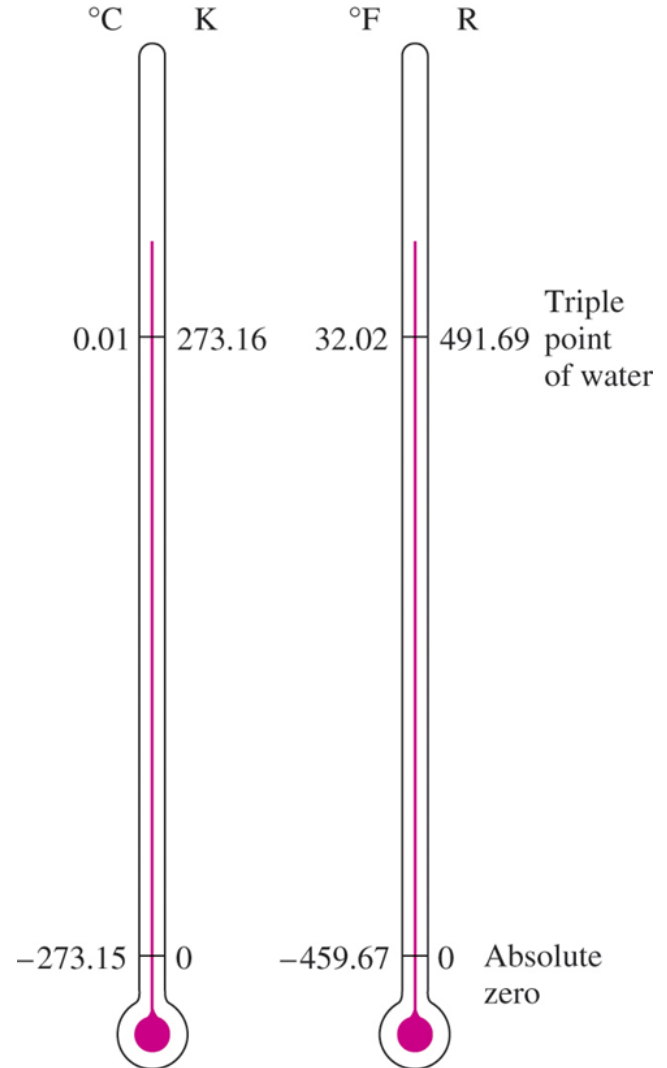
$$T(^{\circ}\text{F}) = 1.8T(^{\circ}\text{C}) + 32$$

$$\Delta T(\text{K}) = \Delta T(^{\circ}\text{C})$$

$$\Delta T(\text{R}) = \Delta T(^{\circ}\text{F})$$



Comparison of magnitudes of various temperature units.



Comparison of temperature scales.

Introduction & Basic Concepts of Thermodynamics

- The reference temperature in the original Kelvin scale was the **ice point**, 273.15 K, which is the temperature at which water freezes (or ice melts).
- The reference point was changed to a much more precisely reproducible point, the **triple point** of water (the state at which all three phases of water coexist in equilibrium), which is assigned the value 273.16 K.

Introduction & Basic Concepts of Thermodynamics

PRESSURE:

Pressure is defined as a normal force exerted by a fluid per unit area. We speak of pressure only when we deal with a gas or a liquid. The counterpart of pressure in solids is normal stress. Since pressure is defined as force per unit area, it has the unit of newton per square meter (N/m^2), which is called a Pascal (Pa). That is,

$$1 \text{ Pa} = 1 \text{ N/m}^2$$

The pressure unit Pascal is too small for pressures encountered in practice. Therefore, its multiples kilopascal ($1 \text{ kPa} = 10^3 \text{ Pa}$) and mega Pascal ($1 \text{ MPa} = 10^6 \text{ Pa}$) are commonly used. Three other pressure units commonly used in practice, especially in Europe, are bar, standard atmosphere, and kilogram-force per square centimeter:

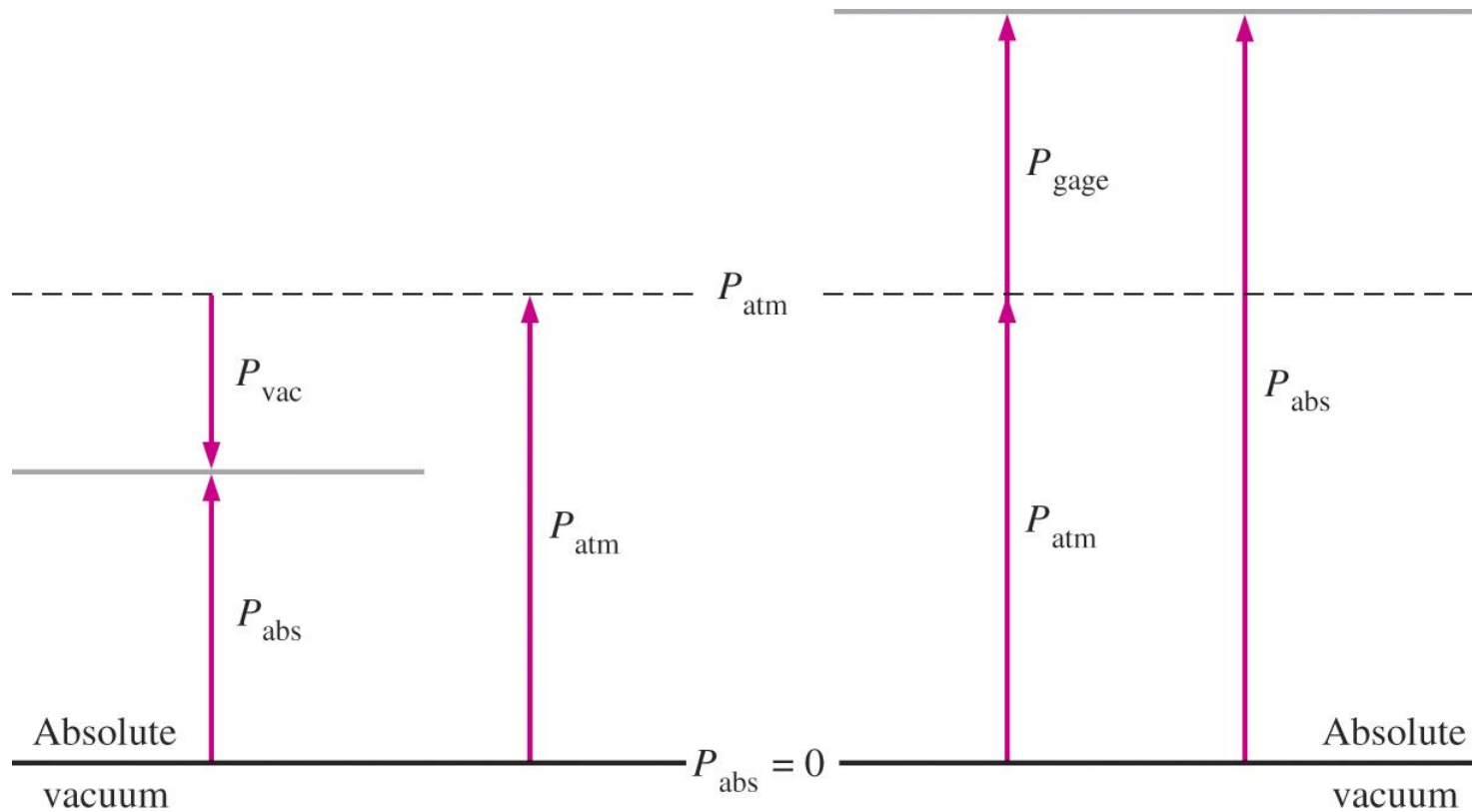
$$1 \text{ bar} = 10^5 \text{ Pa} = 0.1 \text{ MPa} = 100 \text{ kPa} : 1 \text{ atm} = 101,325 \text{ Pa} = 101.325 \text{ kPa} = 1.01325 \text{ bars}$$

$$1 \text{ kgf/cm}^2 = 9.807 \text{ N/cm}^2 = 9.807 \times 10^4 \text{ N/m}^2 = 9.807 \times 10^4 \text{ Pa} = 0.9807 \text{ bar} = 0.9679 \text{ atm}$$

Introduction & Basic Concepts of Thermodynamics

- **Absolute pressure:** The actual pressure at a given position. It is measured relative to absolute vacuum (i.e., absolute zero pressure).
- **Gage pressure:** The difference between the absolute pressure and the local atmospheric pressure. Most pressure-measuring devices are calibrated to read zero in the atmosphere, and so they indicate gage pressure.
- **Vacuum pressures:** Pressures below atmospheric pressure.

Introduction & Basic Concepts of Thermodynamics



$$P_{gage} = P_{abs} - P_{atm}$$

$$P_{vac} = P_{atm} - P_{abs}$$

Introduction & Basic Concepts of Thermodynamics

Variation of Pressure with Depth:

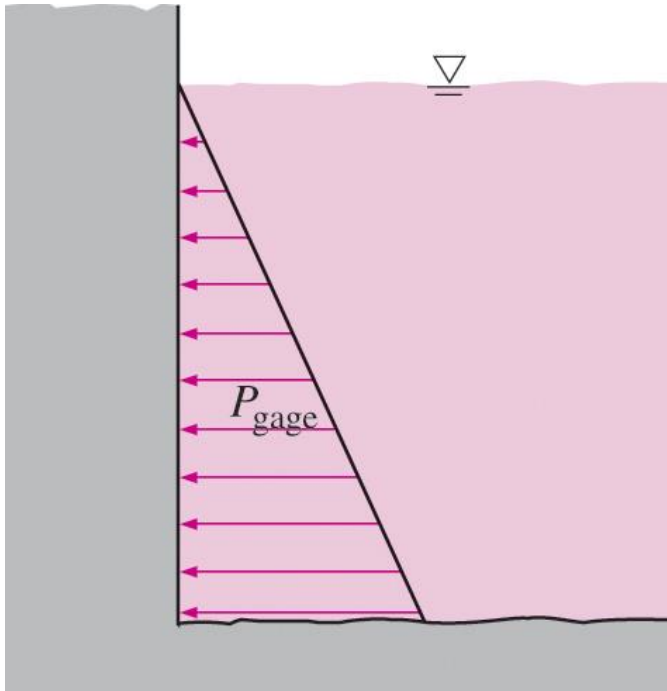
- Pressure in a fluid at rest does not change in the horizontal direction. This can be shown easily by considering a thin horizontal layer of fluid and doing a force balance in any horizontal direction. However, this is not the case in the vertical direction in a gravity field.
- Pressure in a fluid increases with depth because more fluid rests on deeper layers, and the effect of this “extra weight” on a deeper layer is balanced by an increase in pressure.

Introduction & Basic Concepts of Thermodynamics

$$\Delta P = P_2 - P_1 = \rho g \Delta z = \gamma_s \Delta z$$

$$P = P_{atm} + \rho g h$$

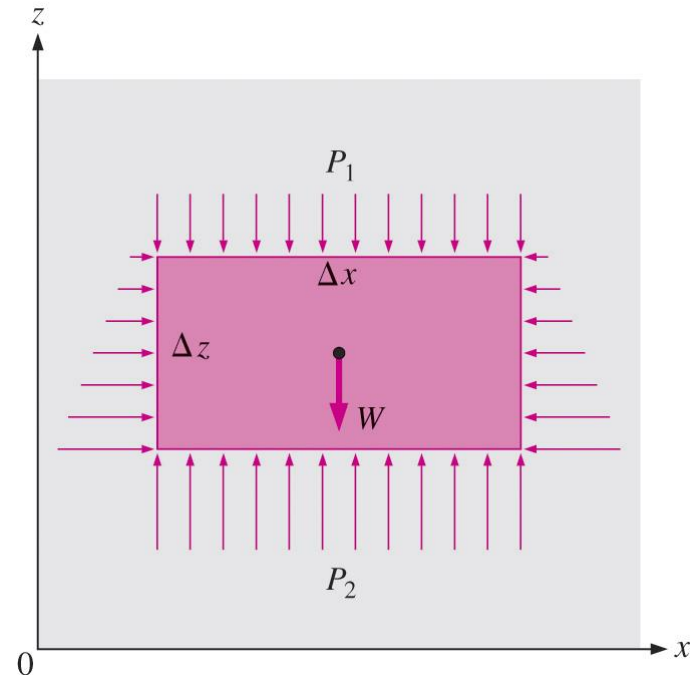
$$P_{gage} = \rho g h$$



The pressure of a fluid at rest increases with depth (as a result of added weight).

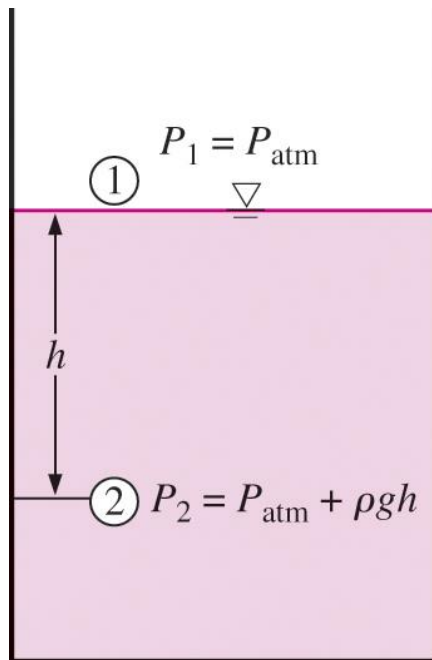
When the variation of density with elevation is known

$$\Delta P = P_2 - P_1 = - \int_1^2 \rho g \Delta z$$



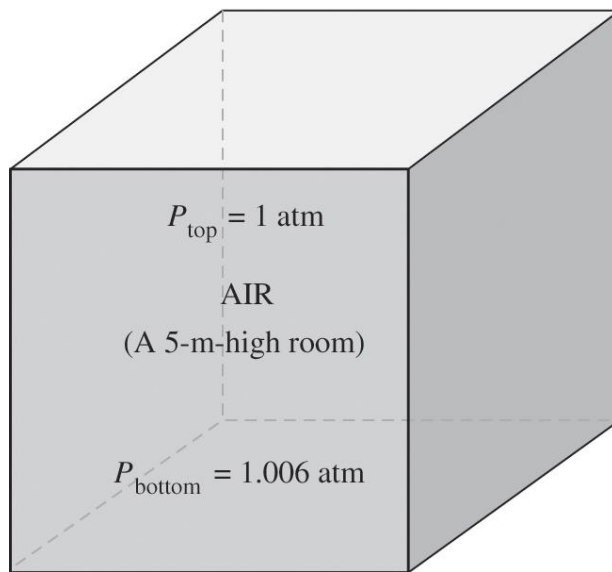
The pressure of a fluid at rest increases with depth (as a result of added weight).

Introduction & Basic Concepts of Thermodynamics



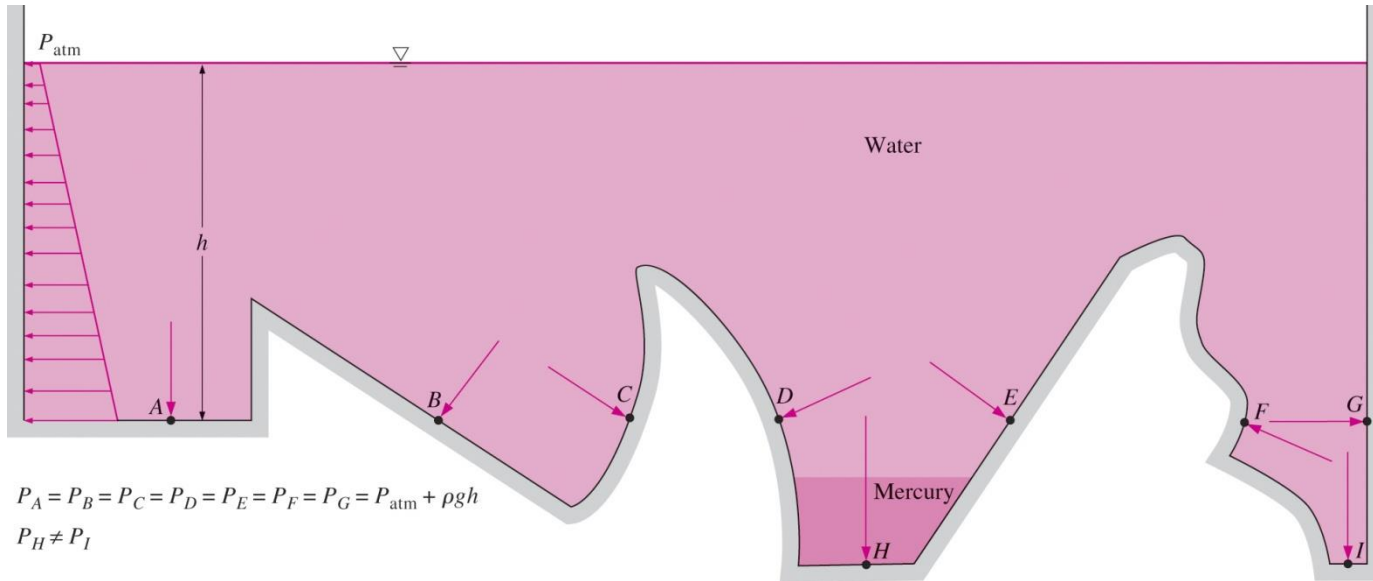
Pressure in a liquid at rest increases linearly with distance from the free surface.

Introduction & Basic Concepts of Thermodynamics



In a room filled with a gas, the variation of pressure with height is negligible.

Introduction & Basic Concepts of Thermodynamics



The pressure is the same at all points on a horizontal plane in a given fluid regardless of geometry, provided that the points are interconnected by the same fluid.

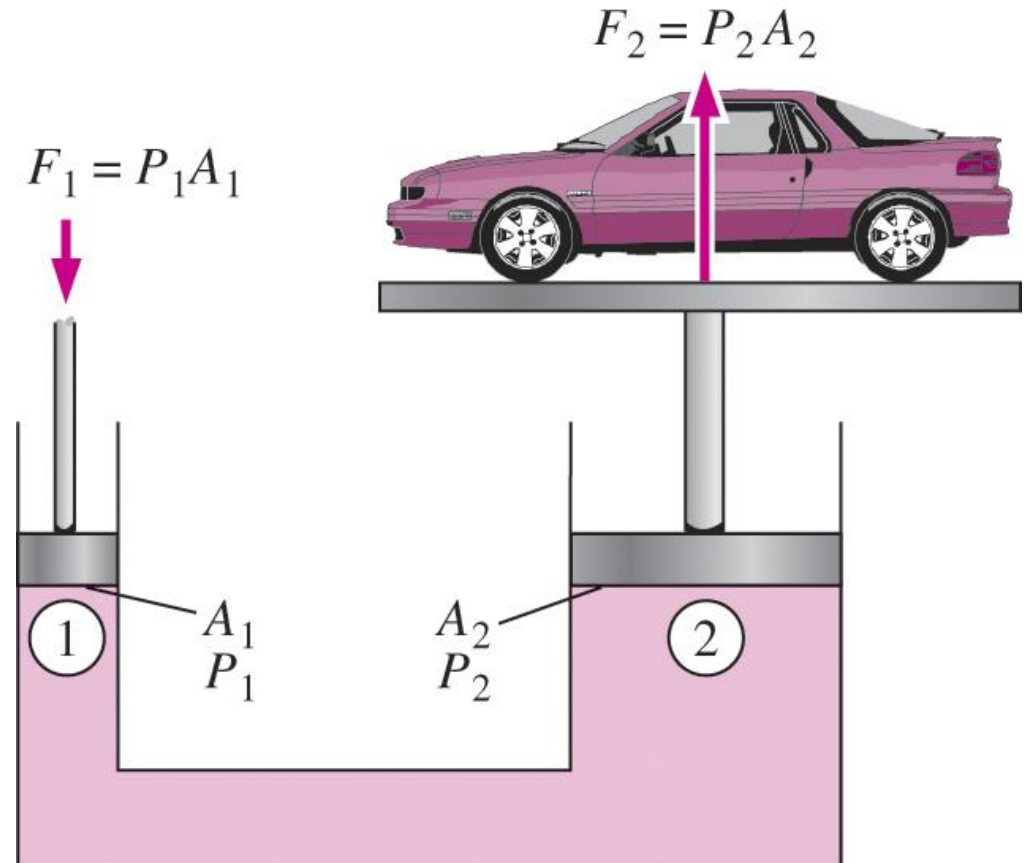
Introduction & Basic Concepts of Thermodynamics

Pascal's law: The pressure applied to a confined fluid increases the pressure throughout by the same amount.

$$P_1 = P_2 \rightarrow \frac{F_1}{A_1} = \frac{F_2}{A_2} \rightarrow \frac{F_2}{F_1} = \frac{A_2}{A_1}$$

The area ratio A_2/A_1 is called the *ideal mechanical advantage* of the hydraulic lift.

Lifting of a large weight by a small force by the application of Pascal's law.



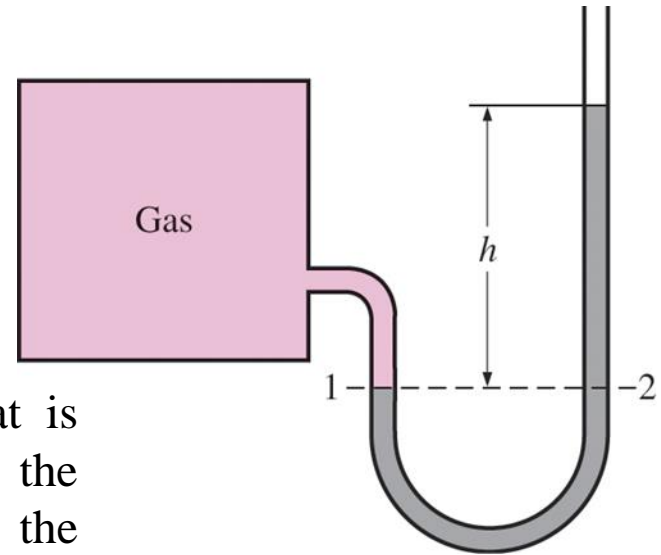
Introduction & Basic Concepts of Thermodynamics

The Manometer:

It is commonly used to measure small and moderate pressure differences. A manometer contains one or more fluids such as mercury, water, alcohol, or oil.

Consider the manometer shown in Fig. that is used to measure the pressure in the tank. Since the gravitational effects of gases are negligible, the pressure anywhere in the tank and at position 1 has the same value. Furthermore, since pressure in a fluid does not vary in the horizontal direction within a fluid, the pressure at point 2 is the same as the pressure at point 1, $P_2 = P_1$.

The differential fluid column of height h is in static equilibrium, and it is open to the atmosphere. Then the pressure at point 2 is determined directly from Eq.



The basic manometer.

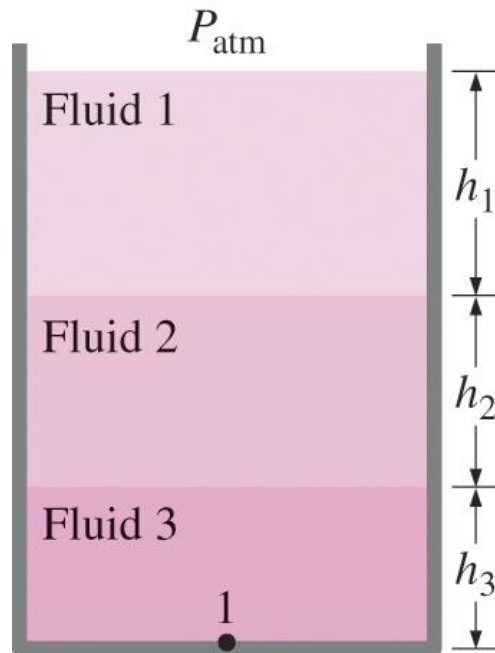
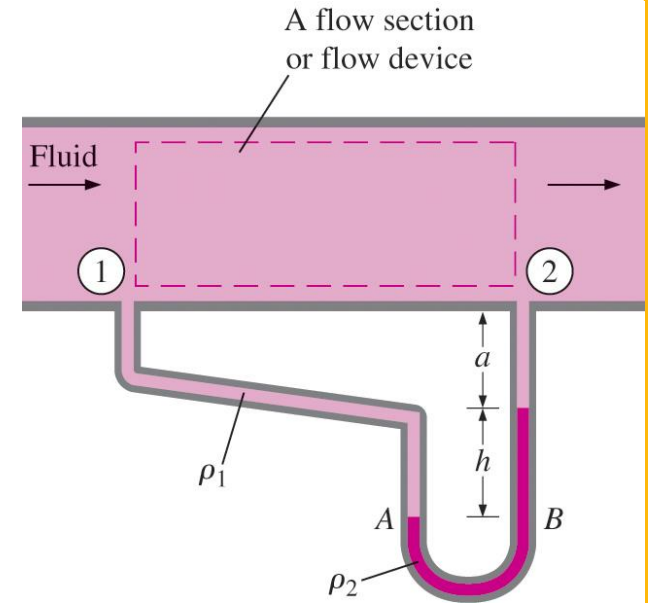
$$P = P_{\text{atm}} + \rho gh$$

Introduction & Basic Concepts of Thermodynamics

Measuring the pressure drop across a flow section or a flow device by a differential manometer.

$$P_1 + \rho_1 g(a + h) - \rho_2 gh - \rho_1 ga = P_2$$

$$P_1 - P_2 = (\rho_2 - \rho_1)gh$$



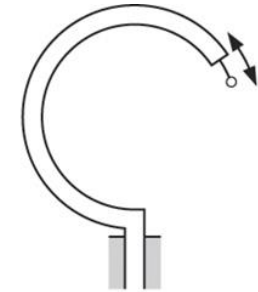
$$P_{atm} + \rho_1 gh_1 + \rho_2 gh_2 + \rho_3 gh_3 = P_1$$

In stacked-up fluid layers, the pressure change across a fluid layer of density ρ and height h is ρgh .

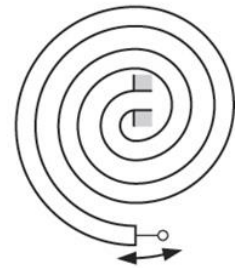
Introduction & Basic Concepts of Thermodynamics

Other Pressure Measurement Devices

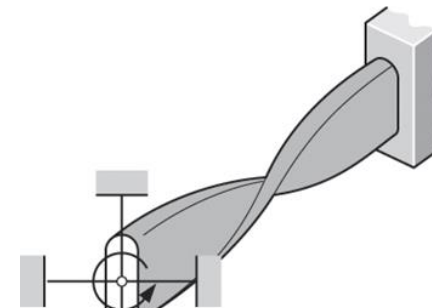
- **Bourdon tube:** Consists of a hollow metal tube bent like a hook whose end is closed and connected to a dial indicator needle.
- **Pressure transducers:** Use various techniques to convert the pressure effect to an electrical effect such as a change in voltage, resistance, or capacitance.
- Pressure transducers are smaller and faster, and they can be more sensitive, reliable, and precise than their mechanical counterparts.
- **Strain-gage pressure transducers:** Work by having a diaphragm deflect between two chambers open to the pressure inputs.
- **Piezoelectric transducers:** Also called **solid-state pressure transducers**, work on the principle that an electric potential is generated in a crystalline substance when it is subjected to mechanical pressure.



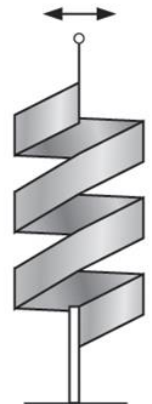
C-type



Spiral



Twisted tube



Helical



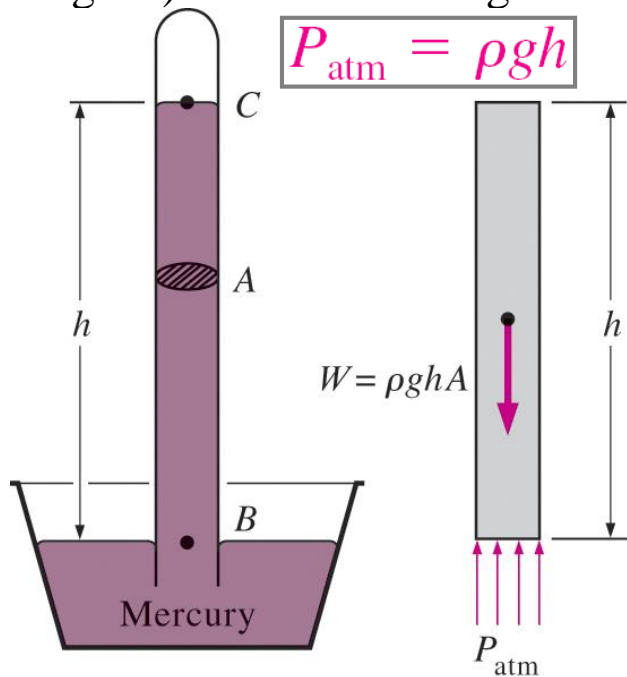
Tube cross section

Various types of Bourdon tubes used to measure pressure.

Introduction & Basic Concepts of Thermodynamics

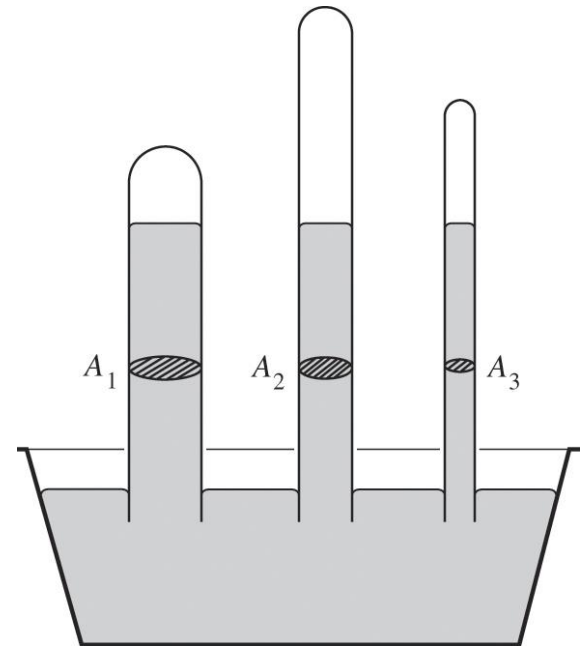
THE BAROMETER AND ATMOSPHERIC PRESSURE:

- Atmospheric pressure is measured by a device called a **barometer**; thus, the atmospheric pressure is often referred to as the **barometric pressure**.
- A frequently used pressure unit is the **standard atmosphere**, which is defined as the pressure produced by a column of mercury 760 mm in height at 0°C ($\rho_{\text{Hg}} = 13,595 \text{ kg/m}^3$) under standard gravitational acceleration ($g = 9.807 \text{ m/s}^2$).



The basic barometer.

The length or the cross-sectional area of the tube has no effect on the height of the fluid column of a barometer, provided that the tube diameter is large enough to avoid surface tension (capillary) effects.





بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

Applied Thermodynamics

Week 02

Instructor: Mr. Adnan Qamar

Mechanical Engineering Department

Reversibility

Reversible Process:

- When a system changes state in such a way that at any instant during the process the state point can be located on the diagram, then the process is said to be *reversible*.
- The fluid undergoing the process passes through a continuous series of equilibrium states. A reversible process between two states can therefore be drawn as a line on any diagram of properties (Fig. 2.1)

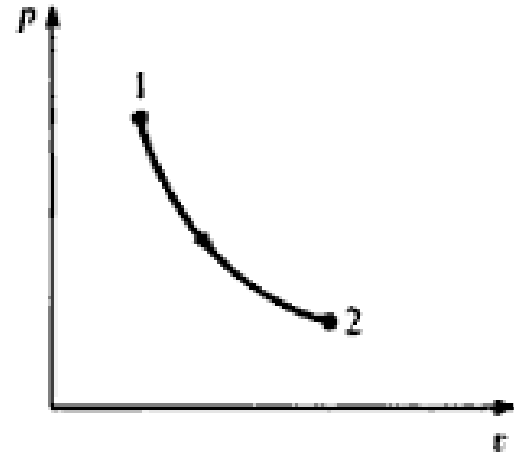


Fig.2.1: Reversible processes

Reversibility

Irreversible Process:

- In practice, the fluid undergoing a process cannot be kept in equilibrium in its intermediate states and a continuous path cannot be traced on a diagram of properties. Such real processes are called *irreversible processes*.
- An irreversible process is usually represented by a dotted line joining the end states to indicate that the intermediate states are indeterminate (Fig. 2.2)

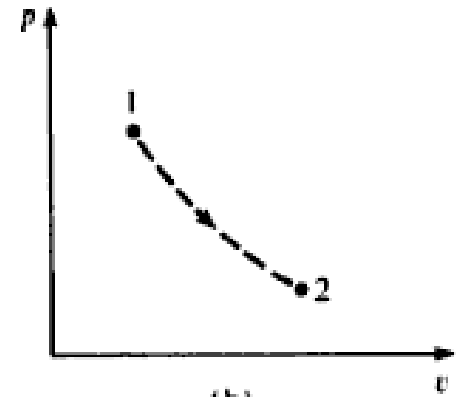


Fig.2.2:Irreversible processes

Reversibility

Reversibility:

A more rigorous definition of reversibility is as follows:

- When a fluid undergoes a reversible process, both the fluid and its surroundings can always be restored to their original state.

The criteria of reversibility are as follows:

- The process must be frictionless. The fluid itself must have no internal friction and there must be no mechanical friction (e.g. between cylinder and piston).
- The difference in pressure between the fluid and its surroundings during the process must be infinitely small. This means that the process must take place infinitely slowly, since the force to accelerate the boundaries of the system is infinitely small.

Reversibility

- The difference in temperature between the fluid and its surroundings during the process must be infinitely small. This means that the heat supplied or rejected to or from the fluid must be transferred infinitely slowly.
- It is obvious from the above criteria that no process in practice is truly reversible. However, in many practical processes a very close approximation to an internal reversibility may be obtained.

Reversibility

Internally Reversible Process:

- In an **internally reversible** process, although the surroundings can never be restored to their original state, the fluid itself is at all times in an equilibrium state and the path of the process can be exactly retraced to the initial state.
- In general, processes in cylinders with a reciprocating piston are assumed to be internally reversible as a reasonable approximation, but processes in rotary machinery (e.g. turbines) are known to be irreversible due to the high degree of turbulence and scrubbing of the fluid.

Reversible work

Consider an ideal frictionless fluid contained in a cylinder behind a piston. Assume that the pressure and temperature of the fluid are uniform and that there is no friction between the piston and the cylinder walls.

Let the cross-sectional area of the piston be A , let the pressure of the fluid be p , let the pressure of the surroundings be $(p + dp)$ (Fig. 2.3).

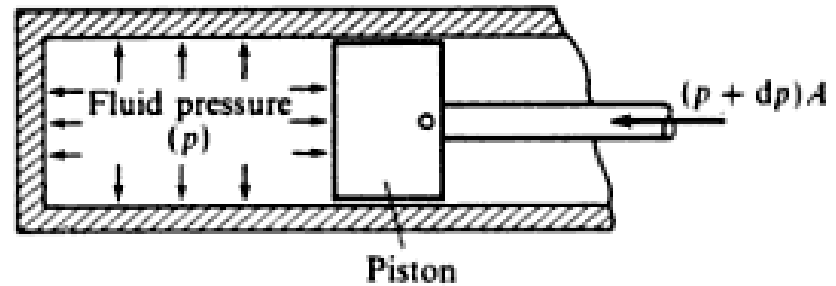


Fig.2.3:Irreversible processes

The force exerted by the piston on the fluid is pA . Let the piston move under the action of the force exerted a distance dl to the left. Then work done on the fluid by the piston is given by force times the distance moved, i.e.

$$\text{Work done} = dW = - (pA) \times dl = -p \times dV = -m \times p \times dv$$

The negative sign indicates that the volume is decreasing,

Reversible work

Work during Reversible Compression Process:

When a fluid undergoes a reversible process a series of state points can be joined up to form a line on a diagram of properties. The work done on the fluid during any reversible process, W , is therefore given by the area under the line of the process plotted on a p - v diagram (Fig. 2.4), i.e.

$$W = -m \int_1^2 p dv = m \int_1^2 p dv = m(\text{Shaded Area In Fig. 2.4})$$

A process from right to left on the p - v diagram is one in which there is a work input to the fluid (i.e. W is positive).

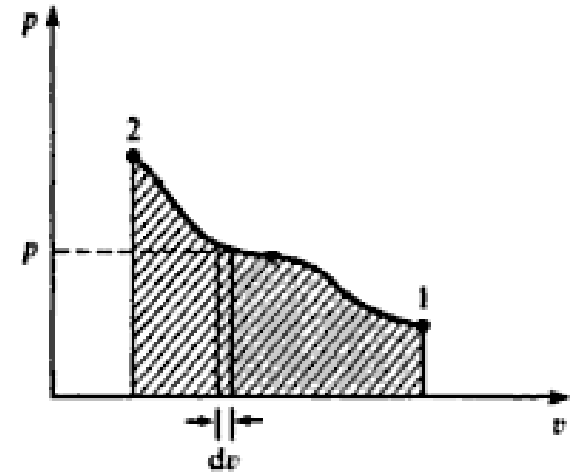


Fig.2.4: Work done in a compression process

Reversible work

Work during Reversible Expansion Process:

When an expansion process takes place reversibly (see Fig. 2.5), the integral, $\int p dv$, is positive, i.e.

$$W = -m \int_1^2 p dv = -m \int_1^2 p dv = -m(\text{Shaded Area In Fig. 2.5})$$

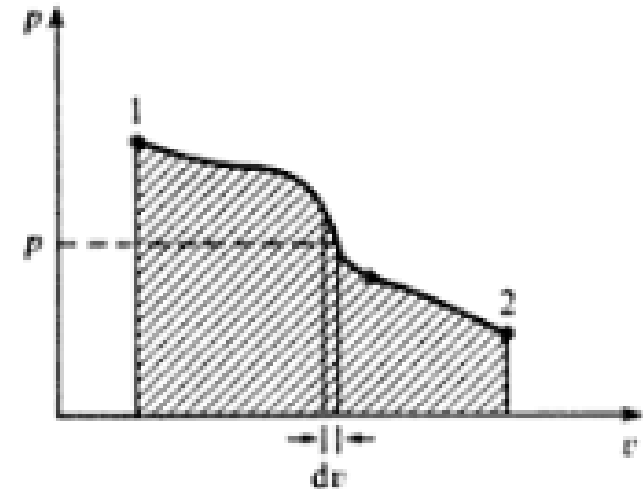


Fig.2.5: Work done in an expansion process

A process from left to right is one in which there is a work output from the fluid (i.e. W is negative).

Reversible Cycle: When a fluid undergoes a series of processes and finally returns to its initial state, then it is said to have undergone a *thermodynamic cycle*. A cycle which consists only of reversible processes is a **reversible cycle**.

Reversible work

Net Work of Cycle: A cycle plotted on a diagram of properties forms a closed figure, and a reversible cycle plotted on a p - v diagram forms a closed figure the area of which represents the **net work** of the cycle.

For example, a reversible cycle consisting of four reversible processes 1 to 2, 2 to 3, 3 to 4, and 4 to 1 is shown in Fig 2.6. The net work input is equal to the shaded area. If the cycle were described in the reverse direction (i.e. 1 to 4, 4 to 3, 3 to 2, and 2 to 1), then the shaded area would represent net work output from the system.

The rule is that the enclosed area of a reversible cycle represents net work input (i.e. net work done on the system) when the cycle is described in an anticlockwise manner, and the enclosed area represents work output (i.e. work done by the system) when the cycle is described in a clockwise manner.

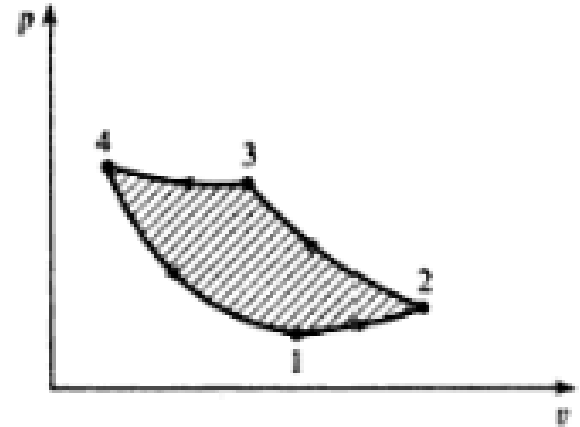


Fig.2.6: Reversible Cycle on p-v diagram

Reversible work

Work during Irreversible Process:

The work is given by $-\int p \, dv$ for a reversible process only. It can easily be shown that $-\int p \, dv$ is not equal to the work done if a process is irreversible.

For example, consider a cylinder, divided into a number of compartments by sliding partitions (Fig.2.7). Initially, compartment A is filled with a mass of fluid at pressure p_1 . When the sliding partition 1 is removed quickly, then the fluid expands to fill compartments A and B. When the system settles down to a new equilibrium state the pressure and volume are fixed and the state can be marked on the p - V diagram (Fig. 2.8). Sliding partition 2 is now removed and the fluid expands to occupy compartments A, B, and C. Again the equilibrium state can be marked on the diagram. The same procedure can be adopted with partitions 3 and 4 until finally the fluid is at p_3 and occupies a volume V_2 when filling compartments A, B, C, D, and E.

Reversible work

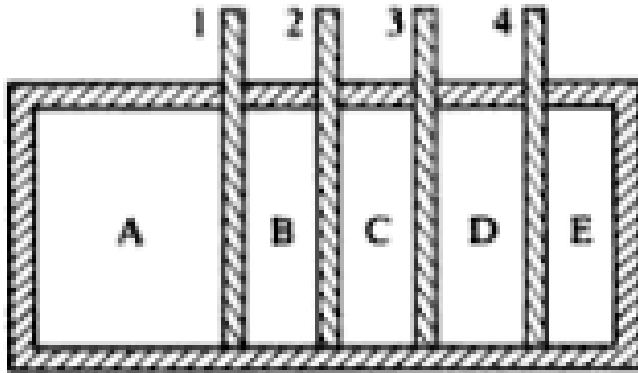


Fig.2.7:Components with sliding partitions

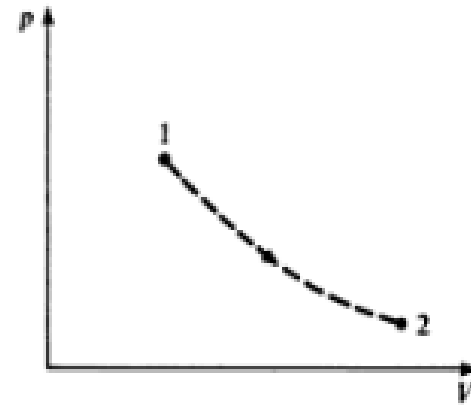


Fig.2.8:Irreversible process on pv diagram

Reversible work

The area under the curve 1-2 on Fig. 2.8 is given by $\int_1^2 p dV$, but no work has been done (apart from the negligible work required to move the partitions). No piston has been moved, no turbine wheel has been revolved; in other words, no external force has been moved through a distance. This is the extreme case of an irreversible process in which $\int p dV$ has a value and yet the work done is zero. When a fluid expands without a restraining force being exerted by the surroundings, as in the example above, the process is known as *free expansion*. Free expansion is highly irreversible. In many practical expansion processes some work is done by the fluid which is less than $\int p dv$ and in many practical compression processes work is done which is greater than $\int p d \int p dv$. It is important to represent all irreversible processes by dotted lines on a p - v diagram as a reminder that the area under the dotted line does not represent work.

Reversible work

Example#01: Unit mass of a fluid at a pressure of 3 bar, and with a specific volume of $18 \text{ m}^3/\text{kg}$, contained in a cylinder behind a piston expands reversibly to a pressure of 0.6 bar according to a law $p = c/v^2$, where c is a constant. Calculate the work done during the process.

Reversible work

Example#02: Unit mass of a certain fluid is contained in a cylinder at an initial pressure of 20 bar. The fluid is allowed to expand reversibly behind a piston according to a law $pV^2 = \text{constant}$ until the volume is doubled. The fluid is then cooled reversibly at constant pressure until the piston regains its original position; heat is then supplied reversibly with the piston firmly locked in position until the pressure rises to the original value of 20 bar. Calculate the net work done by the fluid, for an initial volume of 0.05 m^3 .

