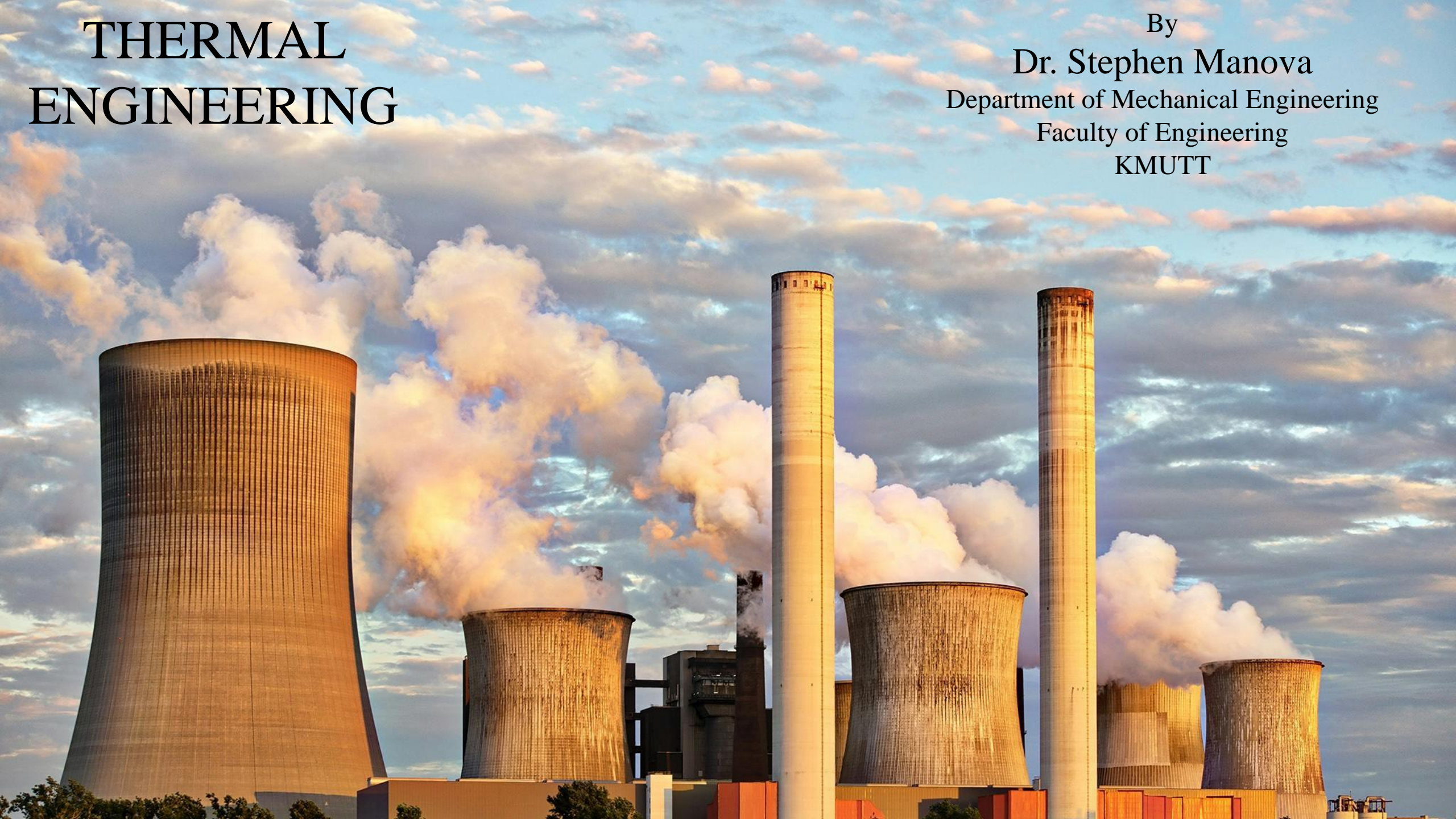


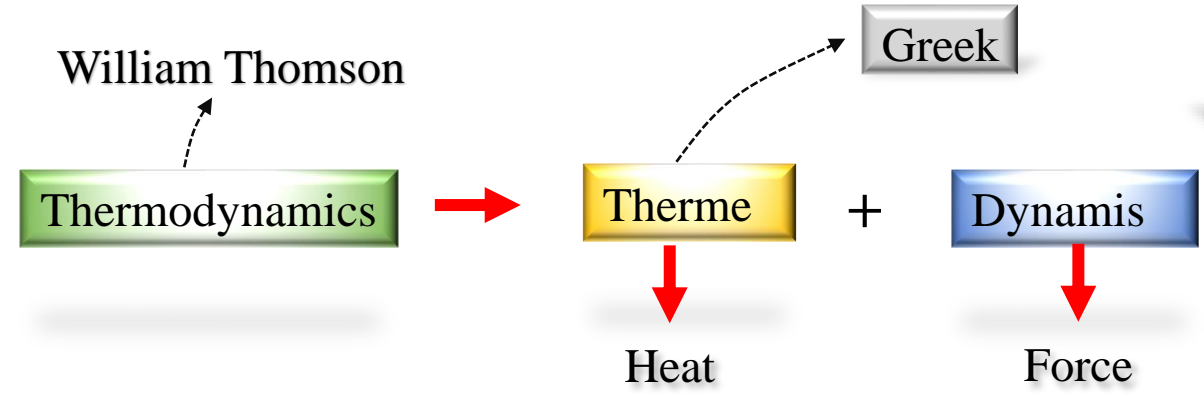
THERMAL ENGINEERING

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Why do we have to study thermodynamics?

Everything in this world is based on **heat energy**. Without heat, **nothing can survive** in this world.



Define thermodynamics?

Thermodynamics is a branch of science, that deals with the relations among heat, work, and the properties of the system, which are in equilibrium.

It also describes the state and the changes in properties.

Fundamental law

Energy can neither be created nor be destroyed, but it can be transformed from one form to the other.
(Law of conservation of energy) [Total energy of universe is constant]

Power generation



Chemical production



Automobile industries



Air conditioning



Food processing



Medical field



Units

Fundamental units

Property	Unit	How to write
Length	Metre	m
Time	Second	s
Mass	Kilogram	kg
Temperature	Celsius, Kelvin, Fahrenheit	°C, K, °F
Light intensity	Candela	cd
Quantity of matter	Mole	mol

Derived units

Property	Unit	How to write
Work	Joule	J
Pressure	Pascal, Bar, Torr	Pa, bar, torr
Energy	Joule	J
Force	Newton	N
Current	Ampere	A
Power	Watt	W
Velocity	Metre per second	m/s
Acceleration	Metre per second square	m/s ²

Multipliers

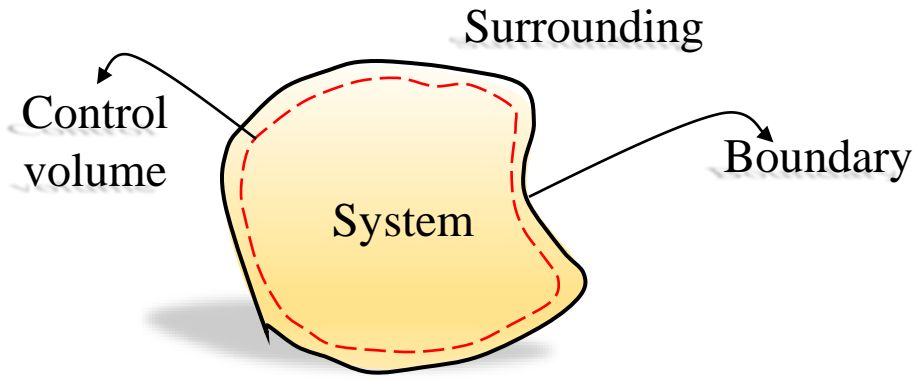
Category	Name
10^1	deka
10^2	hecto
10^3	kilo
10^6	Mega
10^9	Giga
10^{12}	Tera

Common terms we need to know!!

System A well defined mass which can be of any shape.

Surrounding The mass or region outside the system

Boundary The real or imaginary line that separates the system from its surroundings.

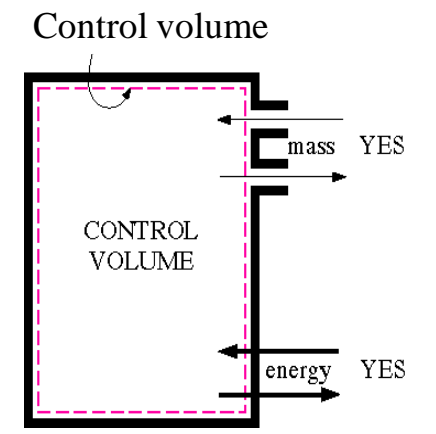


Control volume A quantity of matter or a region in a system, that is chosen for study.

Types of system

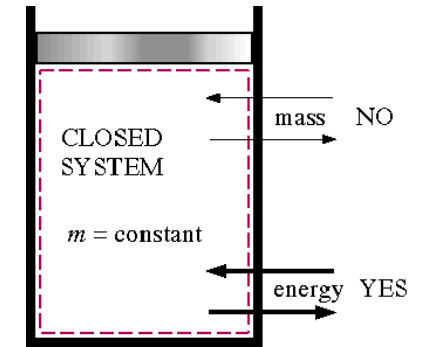
Open system

Both mass and energy can cross the selected boundary



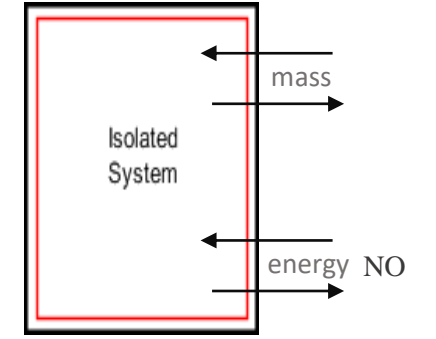
Closed system

Only energy can cross the selected boundary



Isolated system

Neither mass nor energy can cross the selected boundary



Common terms we need to know!!

Properties of system

1. Extensive properties

Properties that depend and vary with mass.

Example: Volume (V), Internal energy (U), Enthalpy (H), Entropy (S) etc.,

2. Intensive properties

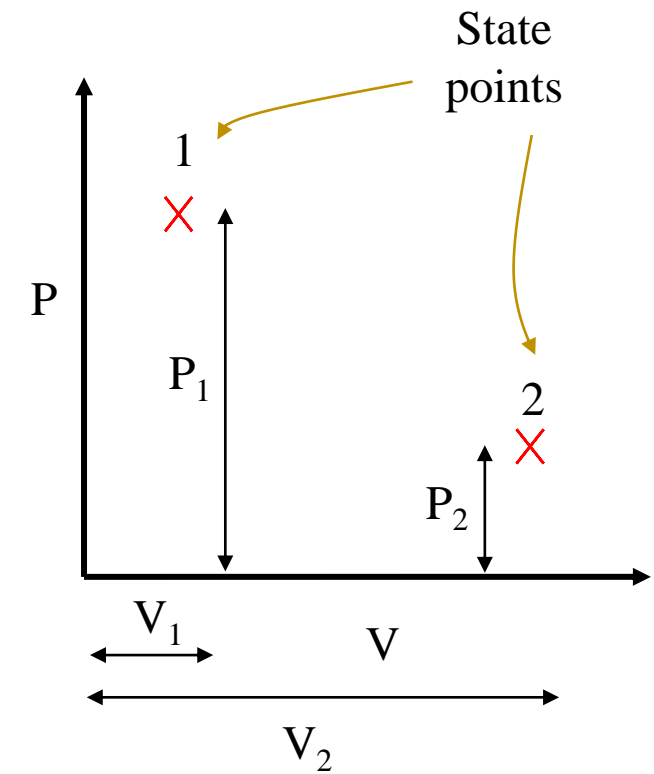
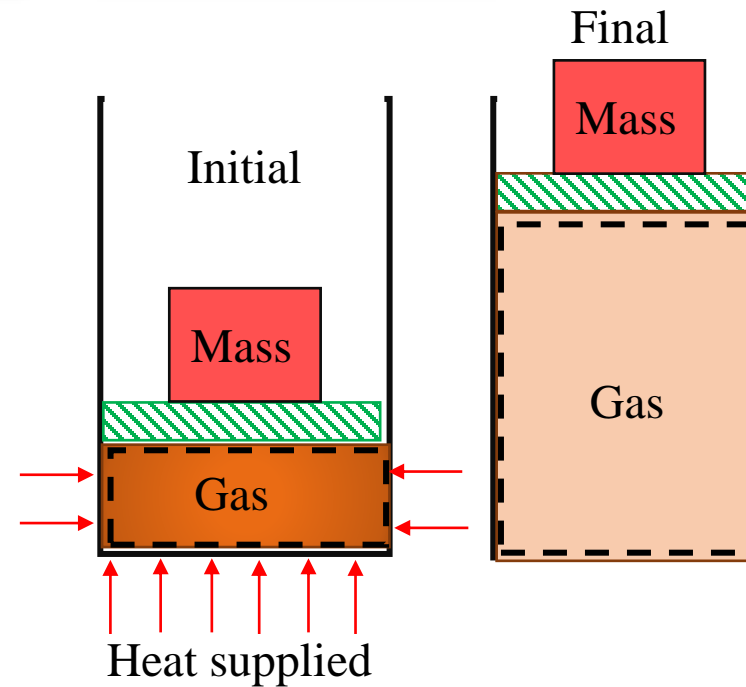
Properties that do not depend and vary with mass.

Example: Temperature (T), Pressure (P), Density (ρ), Specific volume (v), specific enthalpy (h) etc.,

Thermodynamic equilibrium

A system that maintains thermal, mechanical, phase and chemical equilibriums.

Displacement work



Anytime, when there is a deformation in the system boundary, there will be always a **work interaction**

Either, the system does the work to the surrounding or the surrounding does work to the system. This work interaction is the called “**Displacement work**”.

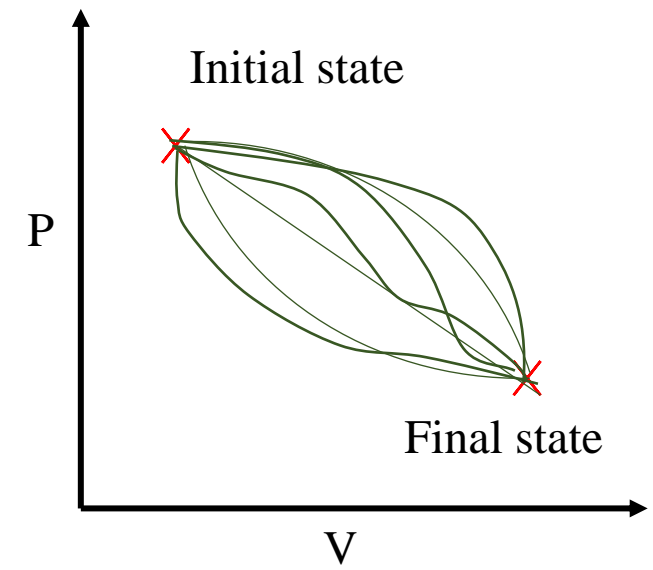
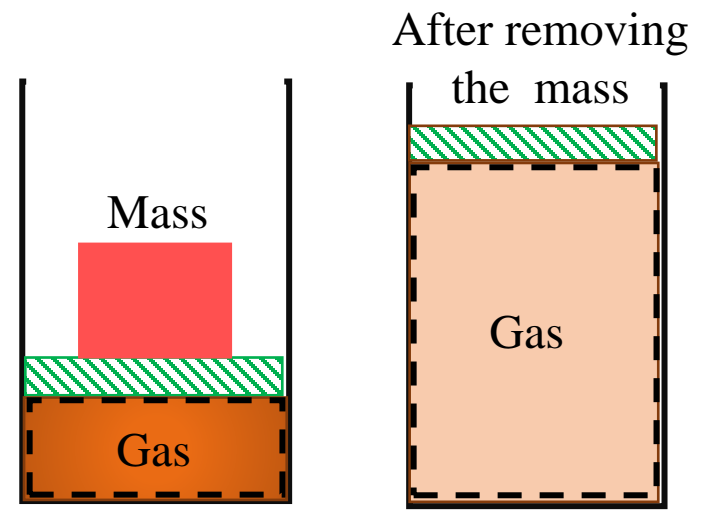
State of a system

Thermodynamic state of a system depends on certain number of independent properties such as pressure, temperature, volume etc. (**Minimum number of properties is 2**)

Thermodynamic process

Thermodynamic process

Case I

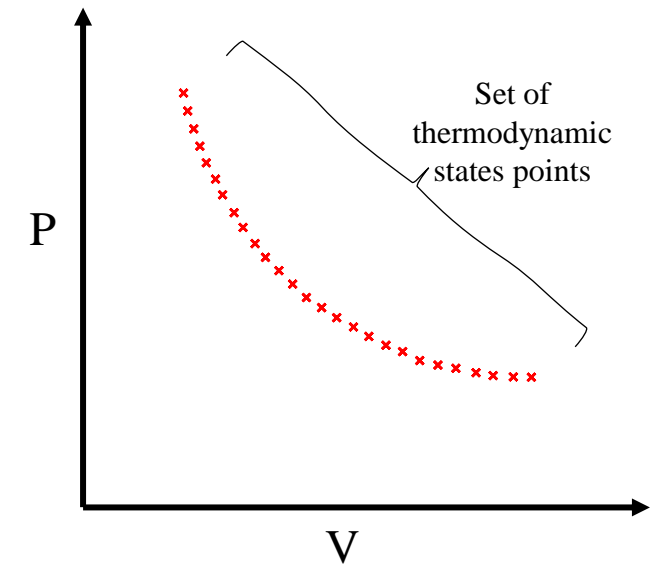
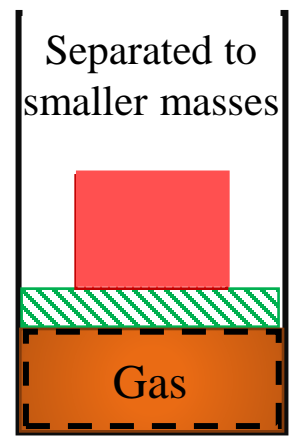


A process is a path that has a set of thermodynamic state points, which are located infinitesimally apart.
Condition: All the state points must be in equilibrium

Quasi static process

A quasi static process is defined as a process in which the properties of the system changes infinitesimally (extremely small)
Note: For non quasi static process, only the end states are in thermodynamic equilibrium state.

Case II



Reversible process

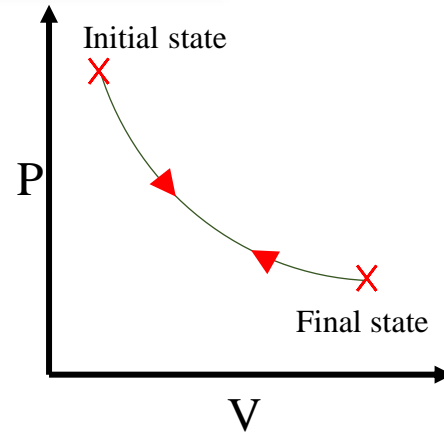
If I again add the masses above the piston, I can retrace the same path, it took before.
 So, if the process follows the same path and there is no change in the system and its boundary, it is called reversible process.

Each point (x) in the curve, indicates a thermodynamic equilibrium state

Types of thermodynamic processes

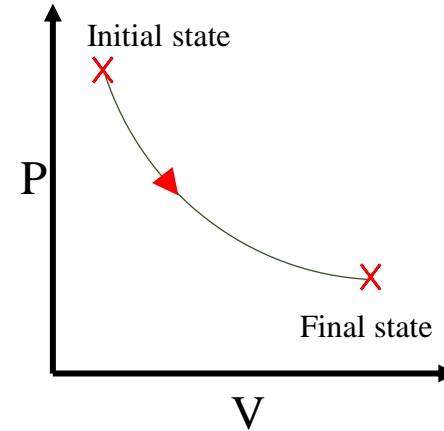
Reversible process

So, if the system follows the same path and there is no change in the system and its boundary, it is called reversible process.



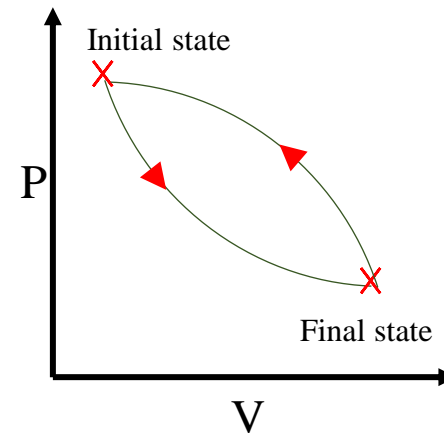
Irreversible process

So, if the process cannot return both the system and its boundary to its initial position, it is called irreversible process.



Cyclic process

When a system undergoes other various processes to return to its initial state, it is called cyclic process.



Adiabatic process

A process that has no heat transfer into or out of the system. It can be considered to be perfectly insulated.

$$\Delta Q = 0$$

Isentropic process

A process where the entropy of the fluid remains constant. Also called as “Reversible adiabatic” process.

Note: No real process are perfectly isentropic.

$$\Delta S = 0$$

Throttling process

A process that has no change in enthalpy and no work is done is called throttling process.

$$\Delta H = 0$$

Thermodynamic approach

What kind of thermodynamic approach we handle to analyse?

Macroscopic approach

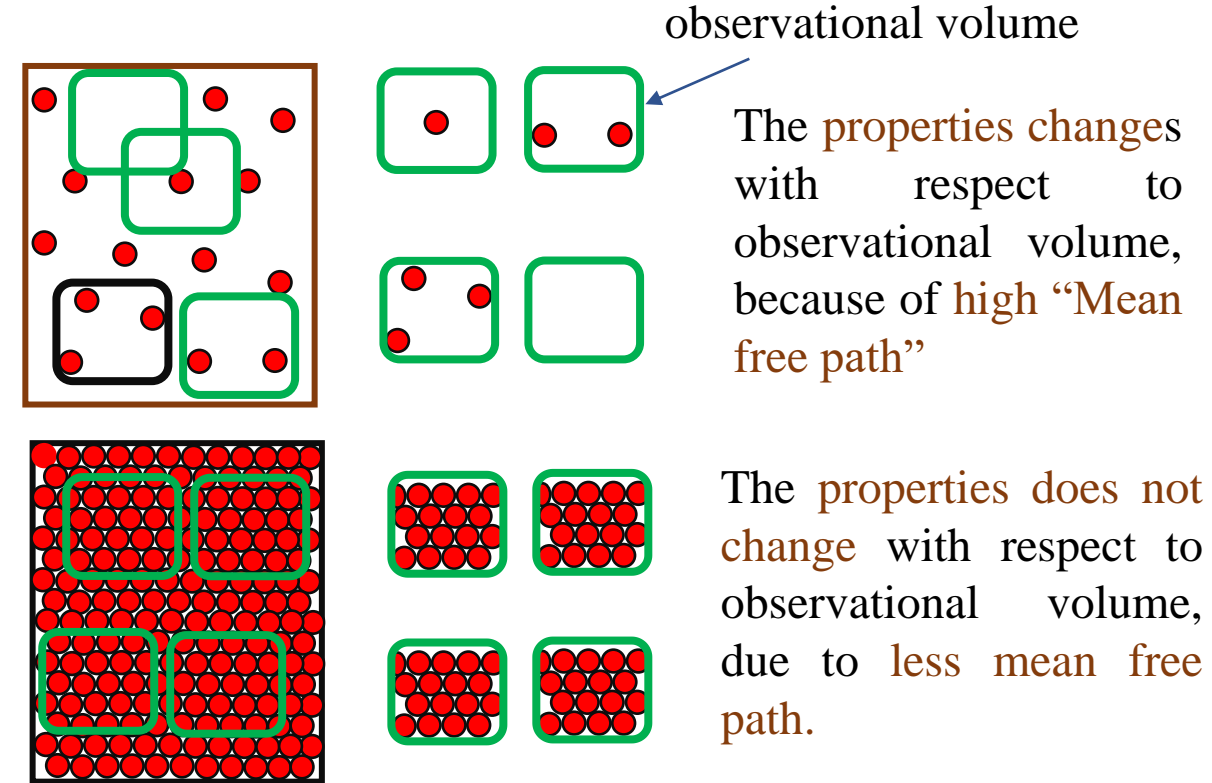
Microscopic approach



- We consider the properties only at the entry and exit points of a system.
- We do not consider about how the process happened internally.
- Changes in molecular level is also not considered.

Concept of continuum

No variation in macroscopic properties like pressure, temperature etc., in the observational volume is called Continuum.



Knudsen number (kn)

$$Kn \leq 10^{-2}$$

Ratio of mean free path (λ) to the characteristic dimension (L) of the system.

Pure substance

What is a pure substance?

- A substance that has an “uniform chemical composition”.
- It may exist in one or multiple phases (Solid, liquid, gas), but if the chemical composition is the same across all phases, it is a pure substance.

Importance in thermodynamics

- To define Pressure – Volume – Temperature relationships.
- To define phase changes such as boiling, condensation, melting and sublimation.
- To easily tabulate the thermophysical properties such as enthalpy, entropy, specific volume, thermal conductivity, specific heat capacity etc.,

Comparison between pure substance and mixture

Property	Pure substance	Mixture
Composition	Fixed and uniform	Variable and can change
Chemical composition	Contains one type of molecule or atom	Contains multiple substances
Phase behavior	Can exist in multiple phases, but it is chemically consistent	Phases may differ chemically or physically
Example	1. Ice, water and Vapor (H ₂ O). 2. Oxygen vapor and liquid Oxygen (O ₂)	1. Air, 2. Salt water 3. C ₂ H ₅ OH + H ₂ O (Vodka)

Temperature Degree of hotness and coldness of a body or a system

Ice point

Water in L
+
Water in S

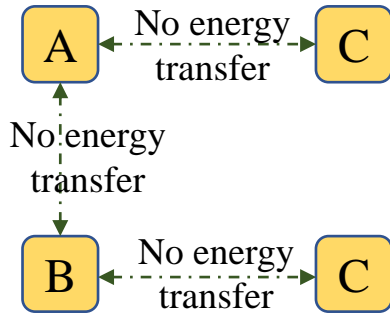
Atmospheric pressure

Boiling point

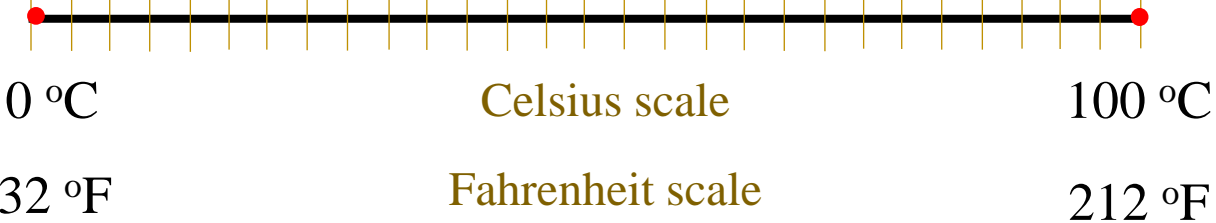
Water in L
+
Water in V

Zeroth law of thermodynamics

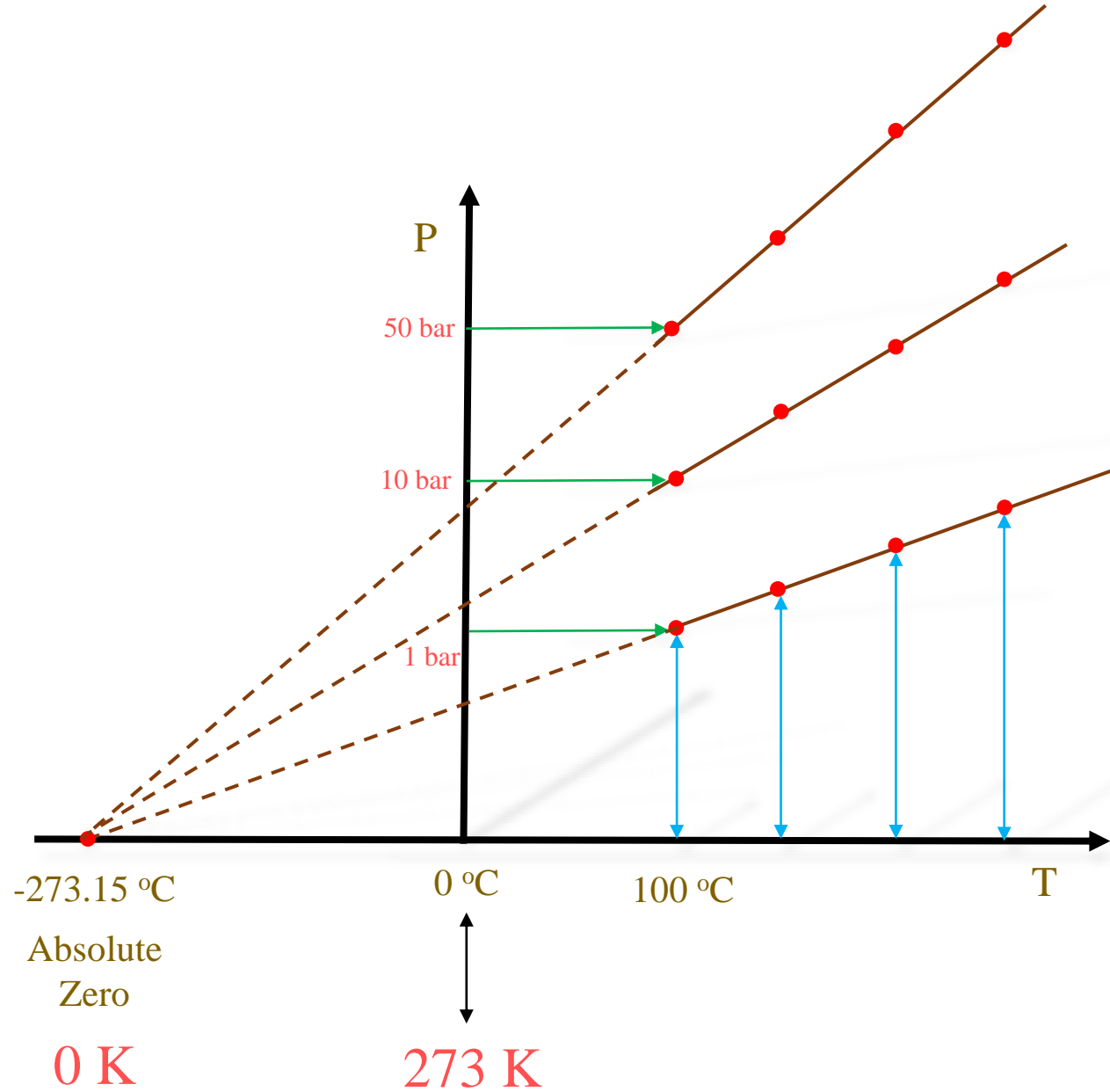
If A and B are in thermal equilibrium with C individually, then A and B are in thermal equilibrium with each other



Water

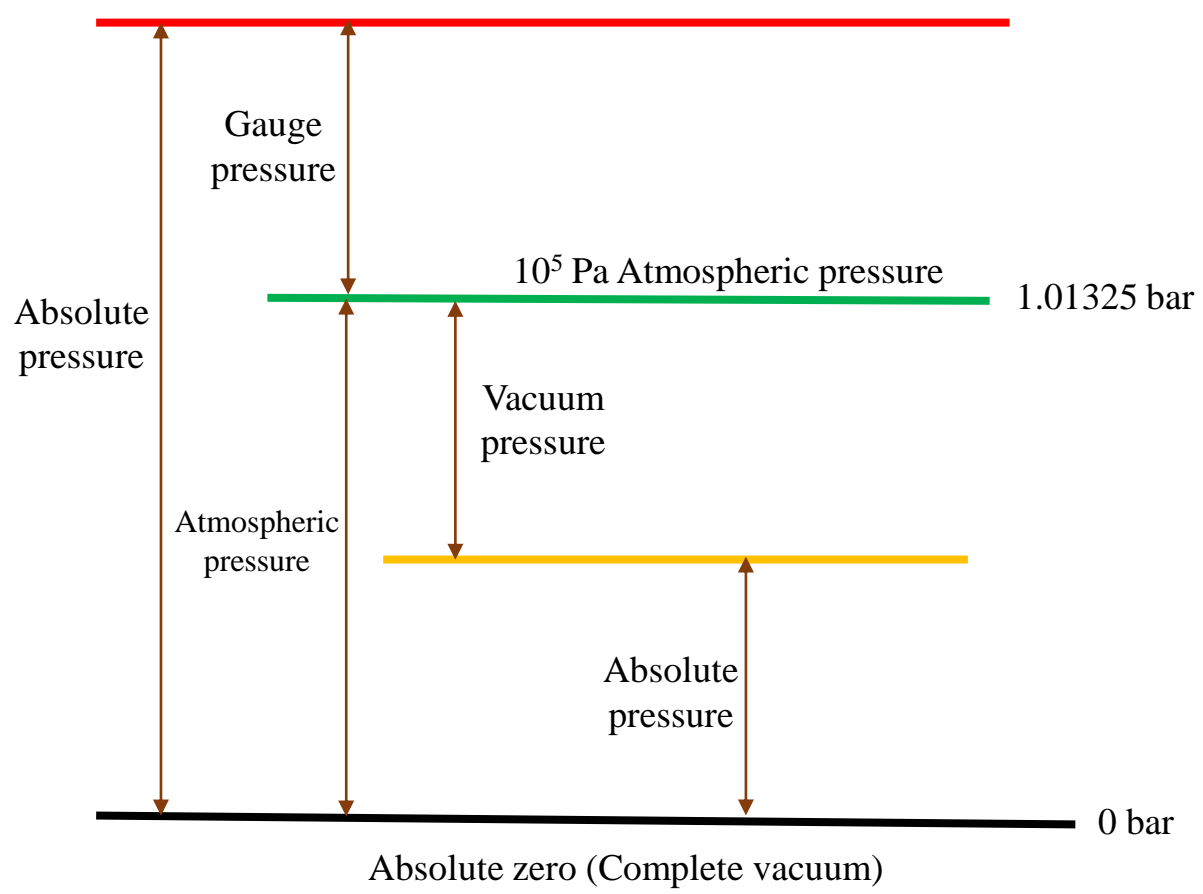


Why thermodynamic temperature scale is called as Kelvin?



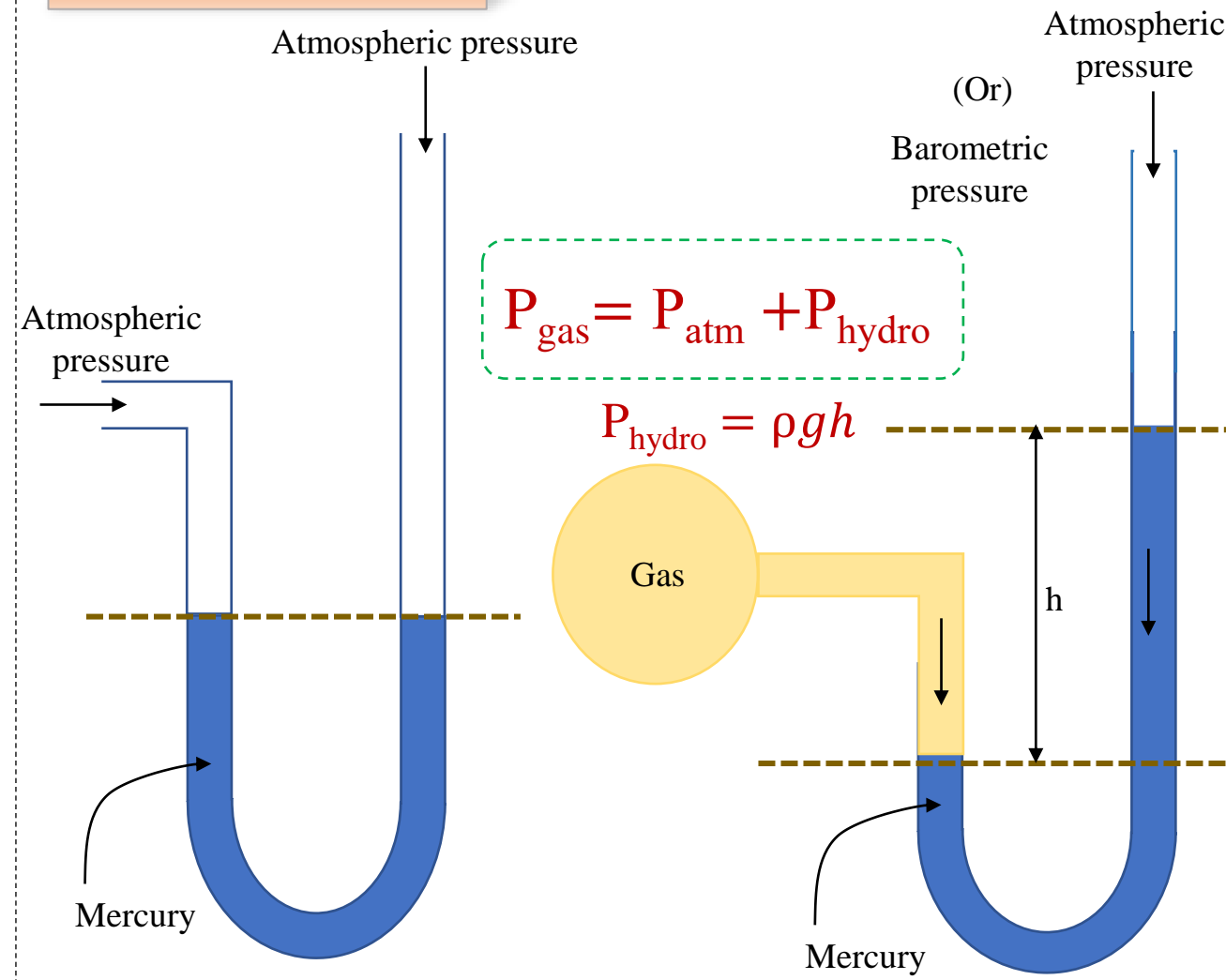
Pressure

Defined as the amount of force acting on an unit area.



U tube manometer

A device to find the pressure of substance



Interesting fact

“1 atmospheric pressure” is roughly an elephant’s weight which is distributed over our body. But we do not feel that. Why?

$$P = \frac{F}{A} = \frac{W}{A} = \frac{m \cdot g}{A} = \frac{\rho \cdot V \cdot g}{A} = \frac{\rho \cdot A \cdot h \cdot g}{A}$$

$$P_{\text{hydro}} = \rho h g$$

Calculations on pressure

1. Convert the following readings of pressure to the required format, assuming that the barometer reads 760 mm of Hg.

(a) 80 cm of Hg to kPa

$$\rho_{\text{Hg}} = 13596 \frac{\text{kg}}{\text{m}^3}$$

Pressure of 760 mm of Hg will be $P_{\text{Hg}} = \rho gh$

$$P_{\text{Hg}} = 13596 \times 9.81 \times \frac{760}{1000}$$

$$P_{\text{Hg}} = 101325 \text{ Pa}$$

(1 atmospheric pressure)

$$P_{\text{Hg}} = 101.325 \text{ kPa}$$

$$80 \text{ cm of Hg} = 800 \text{ mm of Hg}$$

If 760 mm of Hg exerts a pressure of 101.325 kPa, then 800 mm of Hg exerts

$$P_{\text{Hg}} = \frac{800 \times 101.325}{760}$$

(Absolute pressure)

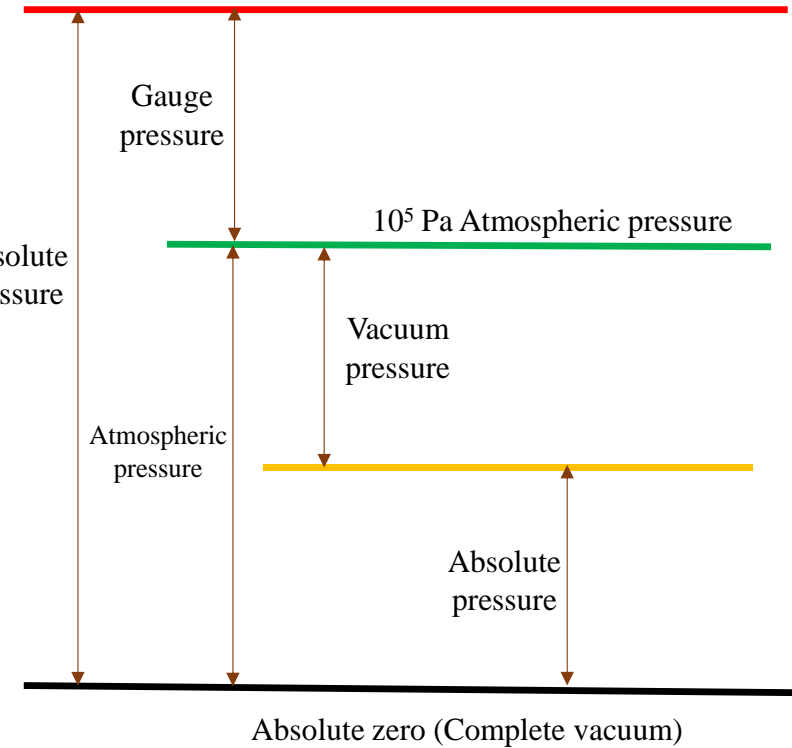
$$P_{\text{Hg}} = 106.65 \text{ kPa}$$

(b) 30 cm of Hg vacuum to kPa

$$\begin{aligned} 30 \text{ cm of Hg vacuum} \\ = \\ 300 \text{ mm of Hg vacuum} \end{aligned}$$

$$\begin{aligned} \text{Absolute pressure} \\ = \\ \text{Atmospheric pressure} \\ - \\ \text{Vacuum pressure} \end{aligned}$$

Absolute pressure



$$\text{Absolute pressure} = 760 \text{ mm} - 300 \text{ mm} = 460 \text{ mm of Hg}$$

If 760 mm of Hg exerts a pressure of 101.325 kPa, then 460 mm of Hg exerts

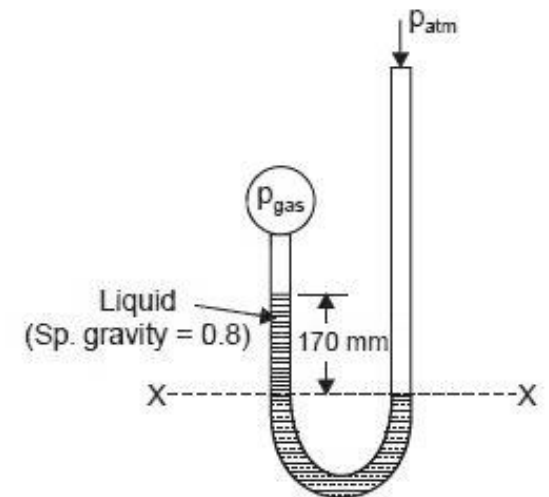
$$P_{\text{Hg}} = \frac{460 \times 101.325}{760}$$

(Absolute pressure)

$$P_{\text{Hg}} = 61.328 \text{ kPa}$$

Calculations on pressure - Assignment

- Convert the following readings of pressure to the required format, assuming that the barometer reads 760 mm of Hg.
 - Pressure due to 1.35m water gauge in bar
 - 50 cm of Hg. Find the absolute pressure in N/m^2 .
- On a piston of 10 cm diameter a force of 1000 N is uniformly applied. Find the pressure on the piston.
- A tube contains an oil of specific gravity 0.9 to a depth of 120 cm. Find the gauge pressure at this depth (in kN/m^2). **Specific gravity = ρ / ρ_w**
- A vessel of cylindrical shape is 50 cm in diameter and 75 cm high. It contains 4 kg of a gas. The pressure measured with manometer indicates 620 mm of Hg above atmosphere, when barometer reads 760 mm of Hg. Determine :
 - The absolute pressure of the gas in bar.
 - Specific volume and density of the gas.
- A U-tube manometer is connected to a gas pipe. The level of the liquid in the manometer arm open to the atmosphere is 170 mm lower than the level of the liquid in the arm connected to the gas pipe. The liquid in the manometer has specific gravity of 0.8. Find the absolute pressure of the gas if the manometer reads 760 mm of Hg.



Units

Fundamental units

Property	Unit	How to write
Length	Metre	m
Time	Second	s
Mass	Kilogram	kg
Temperature	Celsius, Kelvin, Fahrenheit	°C, K, °F
Light intensity	Candela	cd
Quantity of matter	Mole	mol

Derived units

Property	Unit	How to write
Work	Joule	J
Pressure	Pascal, Bar, Torr	Pa, bar, torr
Energy	Joule	J
Force	Newton	N
Current	Ampere	A
Power	Watt	W
Velocity	Metre per second	m/s
Acceleration	Metre per second square	m/s ²

Multipliers

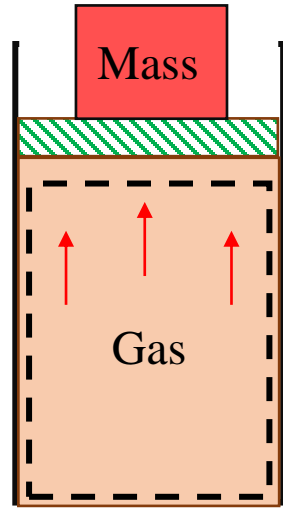
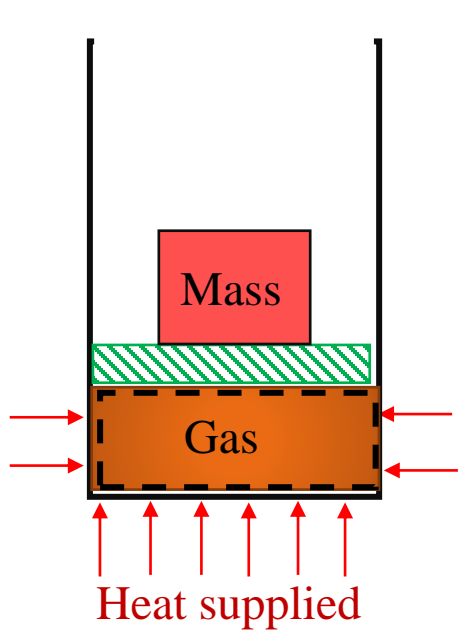
Category	Name
10^1	deka
10^2	hecto
10^3	kilo
10^6	Mega
10^9	Giga
10^{12}	Tera

Work interaction

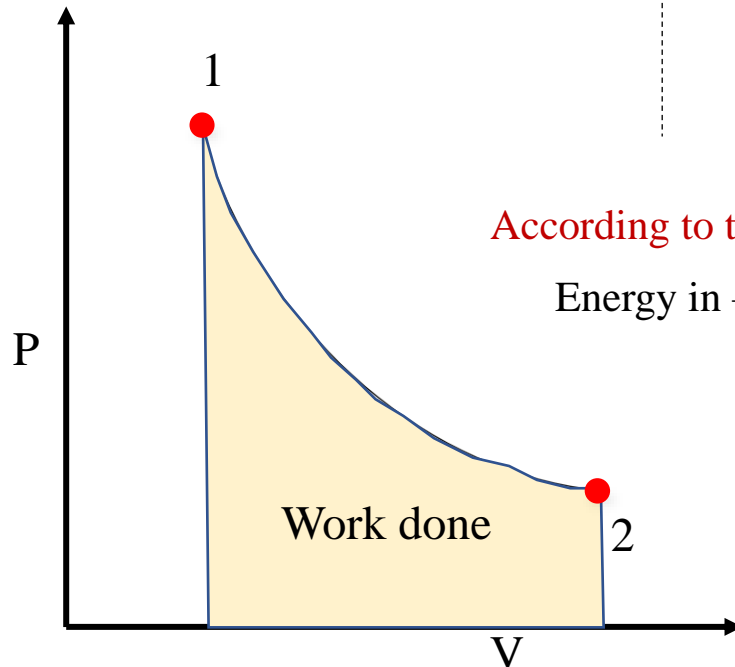
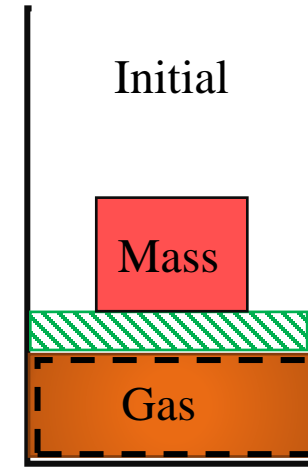
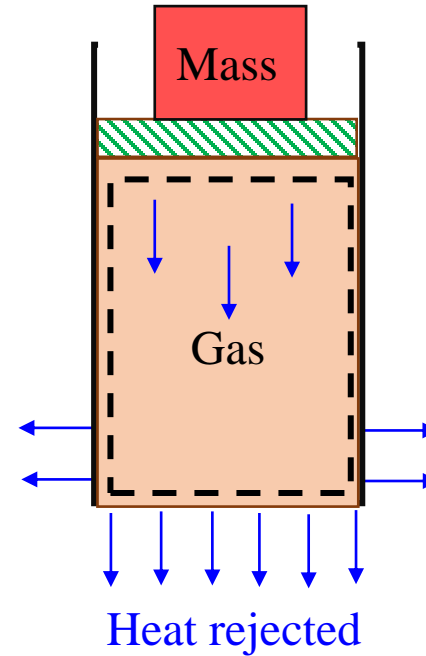
Work done “by the system” is always “+ve”

Work done “to the system” is always “-ve”

System pushes the piston up (system does work)



Surrounding pushes the piston down (surrounding does work)



According to the law of conservation of Energy (1st law of thermodynamics)

Energy in – Energy out = Internal energy of the system

$$Q - W = \Delta U$$

$$\Delta W = P \Delta V$$

$$dW = P dV$$

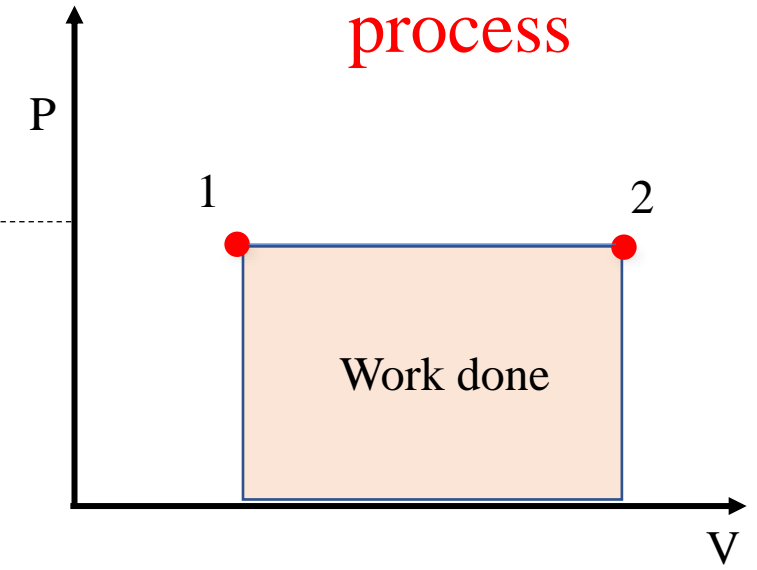
W = Displacement work

P = Pressure

dV = Change in Volume

How to calculate the work, heat and energy for thermodynamics processes?

Constant pressure process



process

$$dQ = mC_p(T_2 - T_1)$$

1. Calculating work done (W)

$$dW = PdV$$

If we integrate both the sides

$$\int_{V_1}^{V_2} dW = \int_{V_1}^{V_2} P dV$$

$$W_{1-2} = \int_{V_1}^{V_2} P dV$$

$$W_{1-2} = P \int_{V_1}^{V_2} dV$$

$$W_{1-2} = P (V_2 - V_1)$$

From ideal gas equation

$$PV = mRT \quad PV_1 = mR T_1$$

$$PV_2 = mR T_2$$

$$W_{1-2} = mR (T_2 - T_1)$$

2. Calculating internal energy (dU)

$$dU = U_2 - U_1 = mC_v (T_2 - T_1)$$

3. Calculating heat supplied (Q)

$$U = Q - W \quad Q = U + W$$

$$dQ = dU + dW$$

$$dQ = mC_v (T_2 - T_1) + mR (T_2 - T_1)$$

$$dQ = m(T_2 - T_1)[C_v + R]$$

From Mayor formula : $R = C_p - C_v$

$$dQ = m(T_2 - T_1)[\cancel{C_v} + C_p - \cancel{C_v}]$$

$$dQ = m(T_2 - T_1)C_p$$

How to calculate the work, heat and energy for thermodynamics processes?

Process	Index n	Heat added	$\int_1^2 p dv$	p, v, T relations	Specific heat, c
Constant pressure	$n = 0$	$c_p(T_2 - T_1)$	$p(v_2 - v_1)$	$\frac{T_2}{T_1} = \frac{v_2}{v_1}$	c_p
Constant volume	$n = \infty$	$c_v(T_2 - T_1)$	0	$\frac{T_1}{T_2} = \frac{p_1}{p_2}$	c_v
Constant temperature	$n = 1$	$p_1 v_1 \log_e \frac{v_2}{v_1}$	$p_1 v_1 \log_e \frac{v_2}{v_1}$	$p_1 v_1 = p_2 v_2$	∞
Reversible adiabatic	$n = \gamma$	0	$\frac{p_1 v_1 - p_2 v_2}{\gamma - 1}$	$p_1 v_1^\gamma = p_2 v_2^\gamma$ $\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{\gamma - 1}$ $= \left(\frac{p_2}{p_1}\right)^{\frac{\gamma - 1}{\gamma}}$	0
Polytropic	$n = n$	$c_n(T_2 - T_1)$ $= c_v \left(\frac{\gamma - n}{1 - n}\right) \times (T_2 - T_1)$ $= \frac{\gamma - n}{\gamma - 1} \times \text{work done (non-flow)}$	$\frac{p_1 v_1 - p_2 v_2}{n - 1}$	$p_1 v_1^n = p_2 v_2^n$ $\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{n - 1}$ $= \left(\frac{p_2}{p_1}\right)^{\frac{n - 1}{n}}$	$c_n = c_v \left(\frac{\gamma - n}{1 - n}\right)$

Graphical representation of steam formation

$$x = \text{Dryness fraction} = \frac{m_g}{m_g + m_f} = \frac{m_g}{m}$$

$$m = \text{Total mass} = m_g + m_f$$

$$h_f = \text{Enthalpy of liquid} = C_{p,f} (T_{\text{final}} - T_{\text{initial}})$$

$$h_g = \text{Enthalpy of dry steam} = h_f + h_{fg}$$

$$h_{fg} = \text{Latent heat} = h_g - h_f$$

$$s_f = \text{Entropy of liquid}$$

$$s_{fg} = s_g - s_f$$

$$s_g = \text{Entropy of vapor}$$

$$v_f = \text{specific volume of liquid}$$

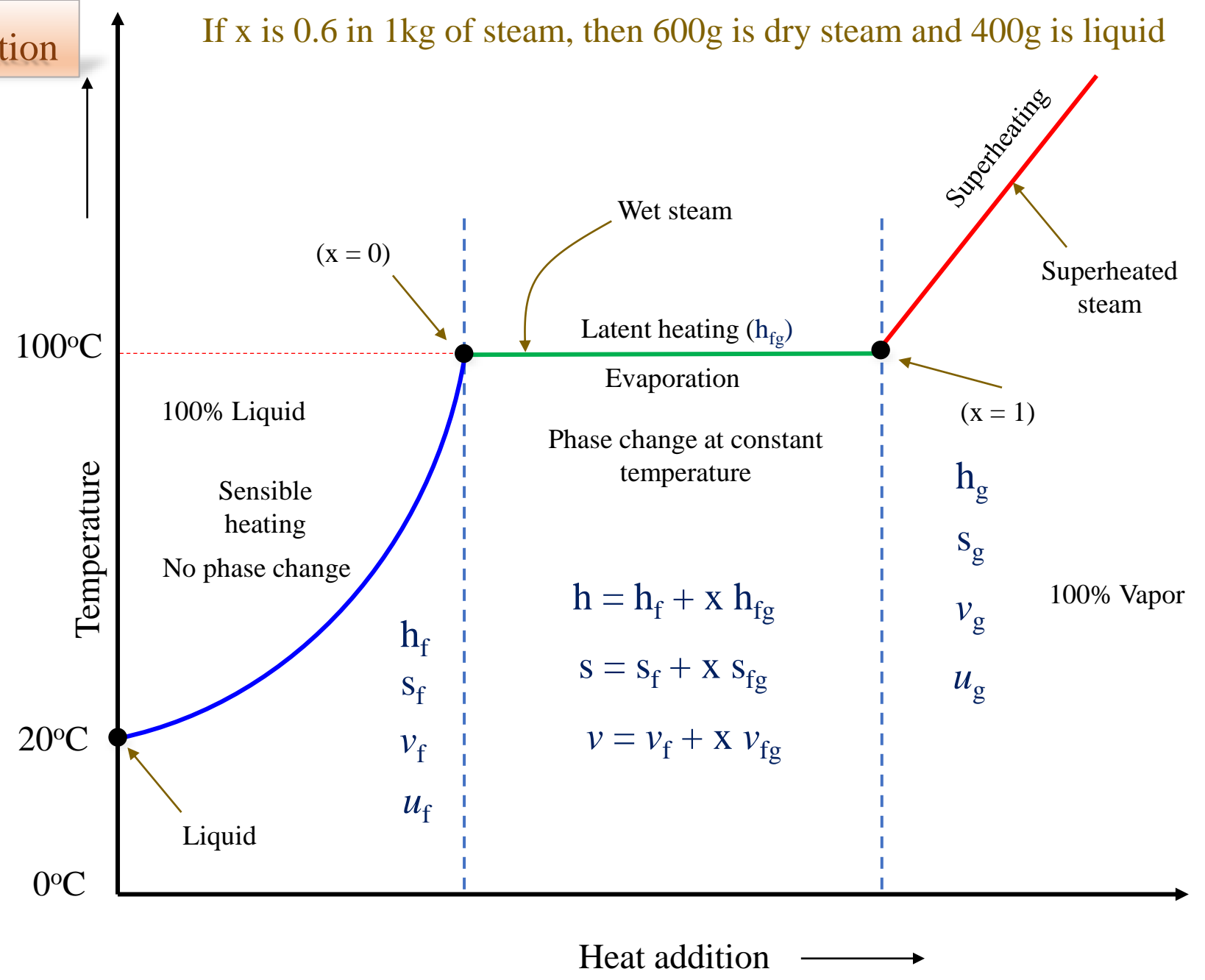
$$v_{fg} = v_g - v_f$$

$$v_g = \text{specific volume of vapor}$$

$$u_f = \text{Internal energy of liquid}$$

$$u_g = \text{Internal energy of vapor}$$

If x is 0.6 in 1kg of steam, then 600g is dry steam and 400g is liquid



Specific volume

If the steam has a dryness fraction of 'x', then 1 kg of the steam contains x kg of **dry steam** and $(1-x)$ kg of **wet steam**.

Specific volume of steam = **Volume of dry steam** + **Volume of wet steam**

$$= xv_g + (1-x)v_f$$

$$= xv_g + v_f - xv_f$$

$$= v_f + x(v_g - v_f)$$

$$v = v_f + x v_{fg}$$

In terms of liquid

$$= v_f + x v_{fg} + v_{fg} - v_{fg}$$

Specific volume of steam = $(v_f + v_{fg}) - (1-x)v_{fg}$

$$v = v_g - (1-x)v_{fg}$$

In terms of vapor

Volume of superheated steam (v_{super})

According to combine gas law equation,

$$\frac{PV}{T} = constant$$

$$\frac{Pv_g}{T_s} = \frac{Pv_{super}}{T_{super}}$$

$$v_{super} = \frac{v_g T_{super}}{T_s}$$

Solving problems

1. A gas undergoes an expansion at constant pressure of 200 kPa, from 0.1 m³ to 0.2m³. It is then expanded to 0.4 m³ and the final pressure is noted as 400 kPa. In the second expansion, the pressure increased linearly with volume. Find the total work done.

Pressure $P_1 = 200$ kPa

Pressure $P_2 = 200$ kPa

Pressure $P_3 = 400$ kPa

To find: Total work done = $W_{1-2} + W_{2-3}$

$$W_{1-2} = \int_{V_1}^{V_2} P dV$$

$$W_{1-2} = P \int_{V_1}^{V_2} dV$$

$$W_{1-2} = P (V_2 - V_1)$$

$$W_{1-2} = 200 (0.2 - 0.1)$$

$$W_{1-2} = 20 \text{ kJ}$$

$$W_{2-3} = \int_{V_2}^{V_3} P dV$$

$$W_{2-3} = \int_{V_2}^{V_3} 1000 V dV$$

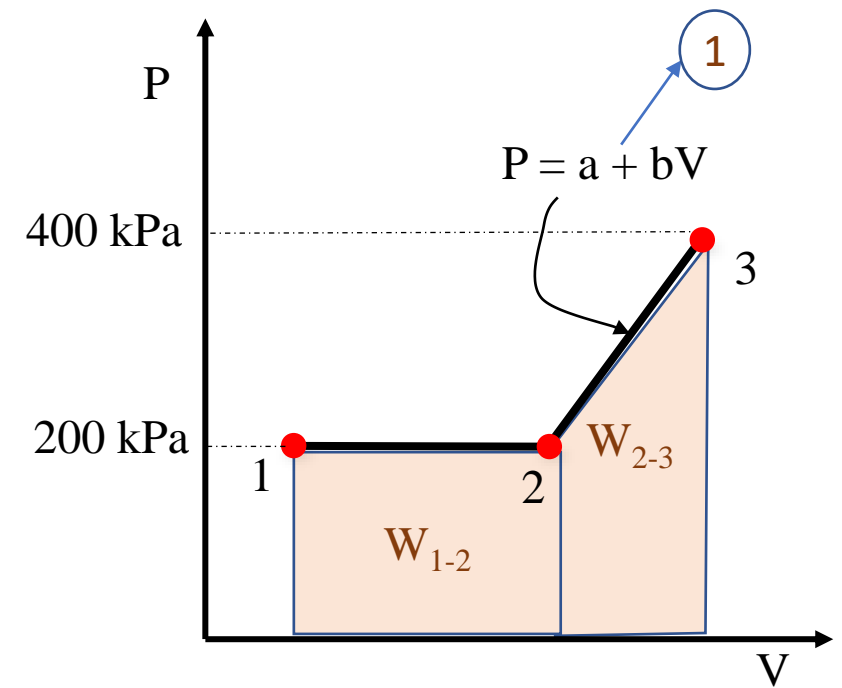
$$W_{2-3} = 1000 \int_{V_2}^{V_3} V dV$$

$$W_{2-3} = 1000 \left[\frac{V_3^2}{2} - \frac{V_2^2}{2} \right]$$

$$W_{2-3} = 1000 \left[\frac{0.4^2}{2} - \frac{0.2^2}{2} \right]$$

$$W_{1-2} = 60 \text{ kJ}$$

$$\text{Total work done} = W_{1-2} + W_{2-3} = 20 \text{ kJ} + 60 \text{ kJ} = 80 \text{ kJ}$$



$$P_2 = a + bV_2$$

$$P_3 = a + bV_3$$

$$200 = a + b \cdot 0.2 \rightarrow \text{2}$$

$$400 = a + b \cdot 0.4 \rightarrow \text{3}$$

By solving the equations 2 and 3, we get,

$$a = 0 \text{ and } b = 1000$$

Substituting the value of a and b in equation 1, we get,

$$P = 1000V$$

Solving problems

2. Calculate the dryness fraction (quality) of steam which has 1.5 kg of water in suspension with 50 kg of steam.

Mass of dry steam $m_g = 50$ kg

Mass of water $m_f = 1.5$ kg

$$\text{Dryness fraction } x = \frac{m_g}{m_g + m_f}$$

Where, $m_g + m_f$ is the total mass (m)

$$\text{Dryness fraction } x = \frac{50}{50 + 1.5}$$

$$\text{Dryness fraction } x = 0.971$$

Solving problems

3. A vessel having a volume of 0.6 m^3 contains 3 kg of liquid water and water vapor mixture in equilibrium at a pressure of 0.5 MPa . Calculate:

- (i) Mass and volume of liquid ;
- (ii) Mass and volume of vapor.

Volume of the vessel $V = 0.6 \text{ m}^3$

Mass of water and water vapor $m = 3 \text{ kg}$

Pressure in the vessel $P = 0.5 \text{ MPa} = 5 \text{ bar}$

To find:

$$x = \frac{m_g}{m_g + m_f} \quad x = \frac{m_g}{m}$$

1. $m_f = m(1-x)$ & $V_f = m_f v_f$

2. $m_g = m(x)$ & $V_g = m_g v_g$

Specific volume $v = \frac{V}{m}$ $v = \frac{0.6}{3} = 0.2 \frac{\text{m}^3}{\text{kg}}$

At the pressure of 5 bar , note the properties of specific volume from steam tables

$$v_g = 0.375 \text{ m}^3/\text{kg}$$

$$v_f = 0.00109 \text{ m}^3/\text{kg}$$

$$v = v_f + x v_{fg}$$

$$v = v_g - (1-x)v_{fg}$$

$$0.2 = 0.375 - (1-x)(0.375-0.00109)$$

$$x = 0.532$$

$$m_f = 1.404 \text{ kg}$$

$$V_f = 0.0015 \text{ m}^3$$

$$m_g = 1.596 \text{ kg}$$

$$V_g = 0.5985 \text{ m}^3$$

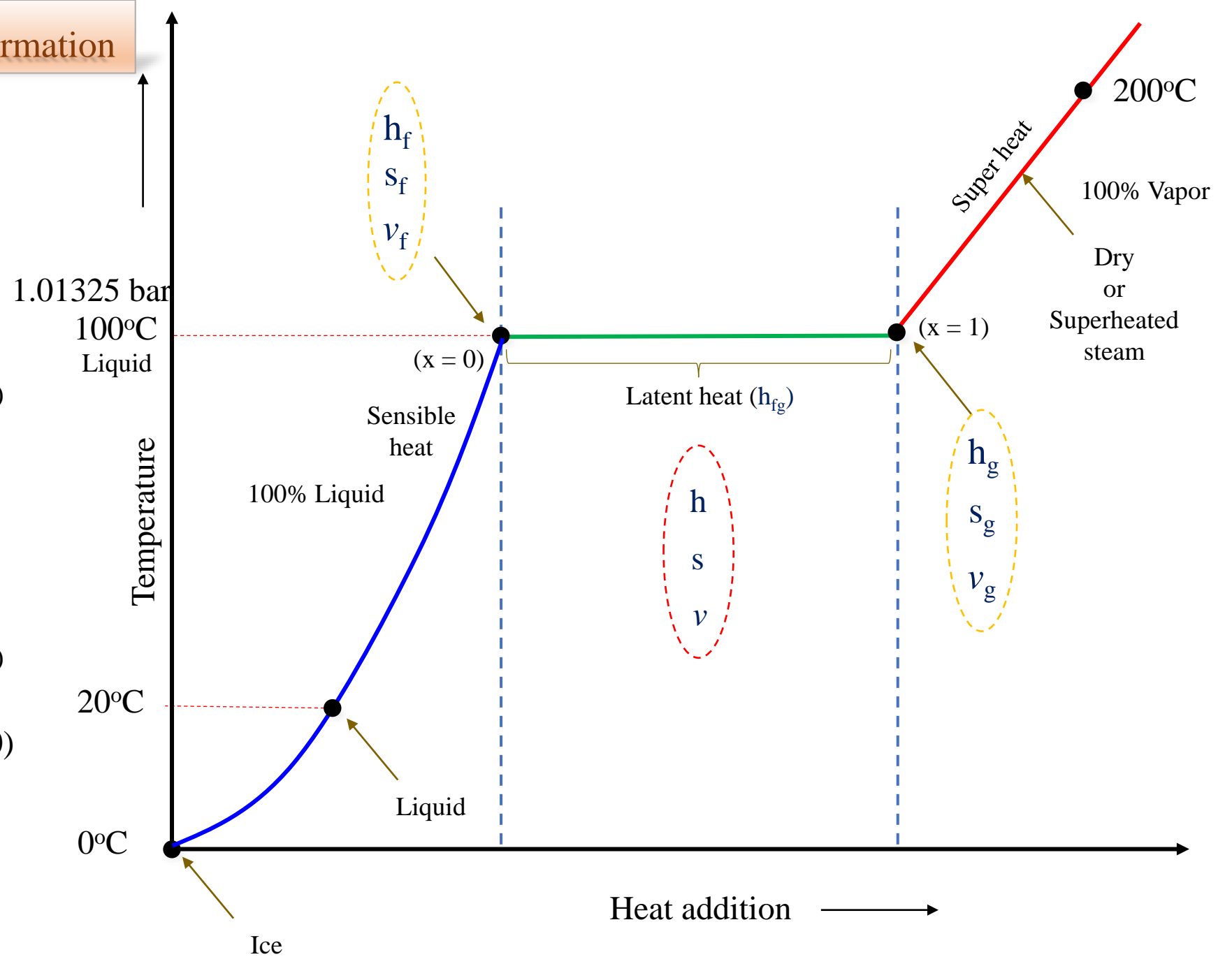
Graphical representation of steam formation

$$x = \text{Dryness fraction} = \frac{m_g}{m_g + m_f} = \frac{m_g}{m}$$

$$m = \text{Total mass} = m_g + m_f$$

$$\begin{aligned} h_f = \text{Enthalpy of liquid} &= C_{p,f} (T_{\text{final}} - T_{\text{initial}}) \\ &= 4.190 (100 - 0) \\ &= 419.0 \text{ kJ/kg} \end{aligned}$$

$$\begin{aligned} h_f = \text{Enthalpy of liquid} &= C_{p,f} (T_{\text{final}} - T_{\text{initial}}) \\ &= 4.190 (100 - 20) \\ &= 335.0 \text{ kJ/kg} \end{aligned}$$



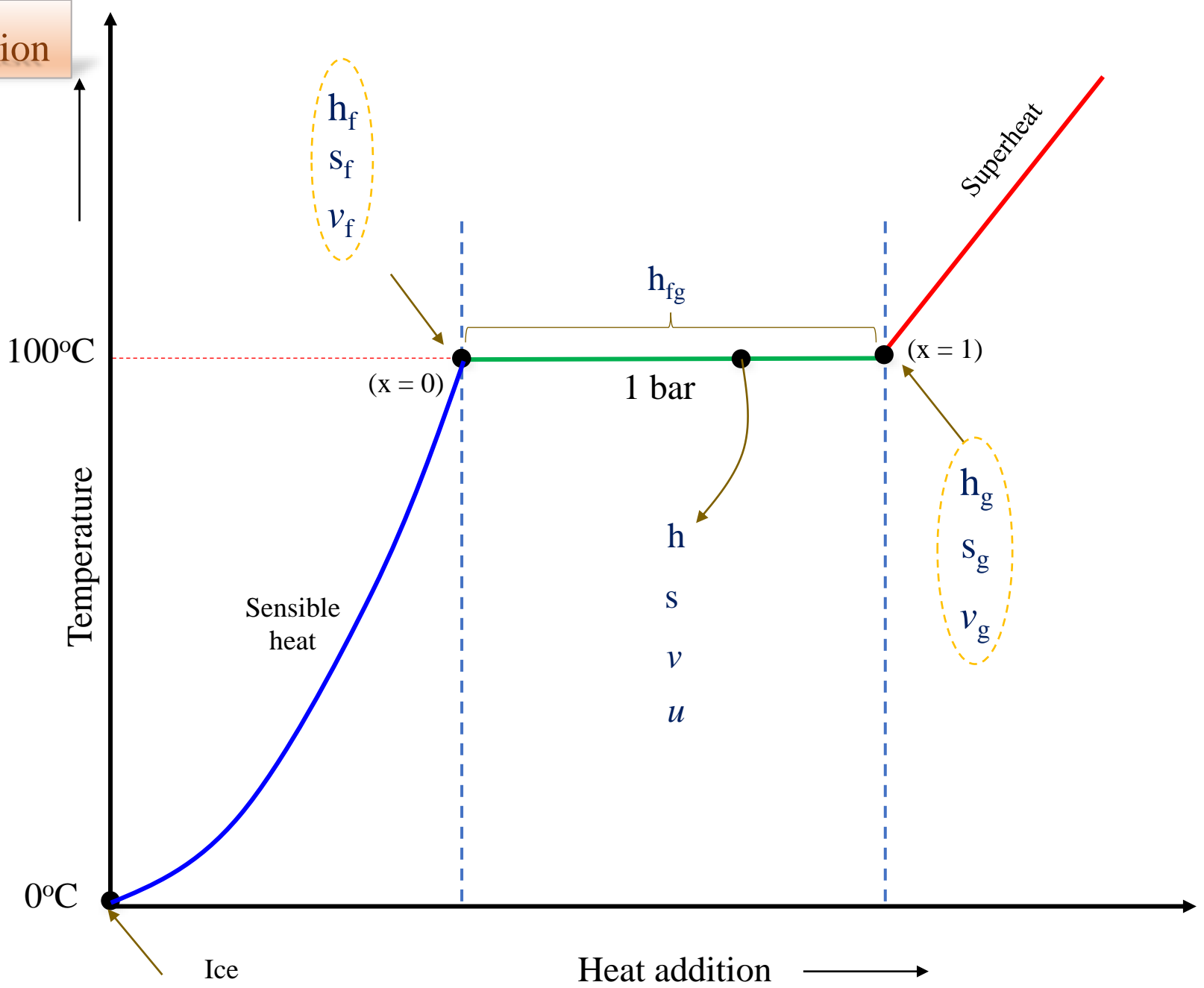
Graphical representation of steam formation

$$h = h_f + x h_{fg}$$

$$s = s_f + x s_{fg}$$

$$v = v_f + x v_{fg}$$

$$u = h - Pv$$



Problem solving

A vessel having a capacity of 0.1 m^3 contains a mixture of saturated water and saturated steam at a temperature of 260°C . The mass of the liquid present is 8 kg . Find the following: (i) The pressure, (ii) The mass, (iii) The specific volume, (iv) The specific enthalpy, (v) The specific entropy, (vi) The specific internal energy.

Given data:

Total Volume $V = 0.1 \text{ m}^3$ $V = V_f + V_g$

Temperature of mixture = 260°C

$m_f = 8 \text{ kg}$

From **Steam tables** note the properties for the **temperature of 260°C**

(1) Pressure inside the vessel $P = 46.943 \text{ bar}$

Specific volume of liquid $v_f = 0.001276 \text{ m}^3/\text{kg}$

Specific volume of vapor $v_g = 0.042134 \text{ m}^3/\text{kg}$

Specific enthalpy of liquid $h_f = 1134.9 \text{ kJ/kg}$

Specific enthalpy of vapor $h_g = 2796.4 \text{ kJ/kg}$

Specific entropy of vapor $s_f = 2.885 \text{ kJ/kg K}$

Specific entropy of vapor $s_g = 6.001 \text{ kJ/kg K}$

(2) The total mass (m) $m = m_g + m_f$

Specific volume $v = \frac{V}{m}$ $v_g = \frac{V_g}{m_g}$ $v_f = \frac{V_f}{m_f}$

$V_f = v_f \times m_f = 0.001276 \times 8$ $V_f = 0.010208 \text{ m}^3$

$V = V_f + V_g$ $0.1 = 0.010208 + V_g$ $V_g = 0.089792 \text{ m}^3$

$v_g = \frac{V_g}{m_g}$ $m_g = \frac{V_g}{v_g}$ $m_g = \frac{0.089792}{0.042134}$

(2) $m_g = 2.1311 \text{ kg}$

$m = m_g + m_f = 8 + 2.1311$ $m = 10.1311 \text{ kg}$

Total Volume $V = 0.1 \text{ m}^3$ $V = V_f + V_g$

Temperature of mixture = 260°C

$m_f = 8 \text{ kg}$ $m_g = 2.1311 \text{ kg}$ $m = 10.1311 \text{ kg}$

From Steam tables note the properties for the temperature of 260°C

(1) Pressure inside the vessel $P = 46.943 \text{ bar}$

Specific volume of liquid $v_f = 0.001276 \text{ m}^3/\text{kg}$

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Specific entropy of vapor $s_f = 2.885 \text{ kJ/kg K}$

Specific entropy of vapor $s_g = 6.001 \text{ kJ/kg K}$

(iii) The specific volume (v) $v = v_f + x v_{fg}$ $v = v_g - (1 - x)v_{fg}$

$$x = \frac{m_g}{m_g + m_f} \quad x = \frac{2.1311}{10.1311} \quad x = 0.210$$

$$v = v_f + x v_{fg} \quad v = 0.001276 + [0.210 \times (0.042134 - 0.001276)] \quad v = 0.00985 \text{ m}^3/\text{kg}$$

(iv) The specific enthalpy (h) $h = h_f + x h_{fg}$

$$h = h_f + x h_{fg} = 1134.9 + (0.210 \times 1661.5) \quad h = 1483.815 \text{ kJ/kg}$$

(v) The specific entropy (s) $s = s_f + x s_{fg}$

$$s = s_f + x s_{fg} = 2.885 + (0.210 \times 3.116) \quad s = 3.5393 \text{ kJ/kg K}$$

(vi) The specific internal energy (u). $H = U + PV$

$$h = u + pv \quad u = h - pv \quad u = 1483.815 - (46.943 \times 100 \times 0.00985)$$

$$u = 1437.576 \text{ kJ/kg}$$

First law of thermodynamics applied for a steady flow

u = Internal Energy (J/kg)

p = Pressure of the fluid (N/m²)

c = Velocity of fluid (m/s)

v = specific volume of the fluid (m³/kg)

h = Enthalpy of the fluid (J/kg)

z = Height from the datum line (m)

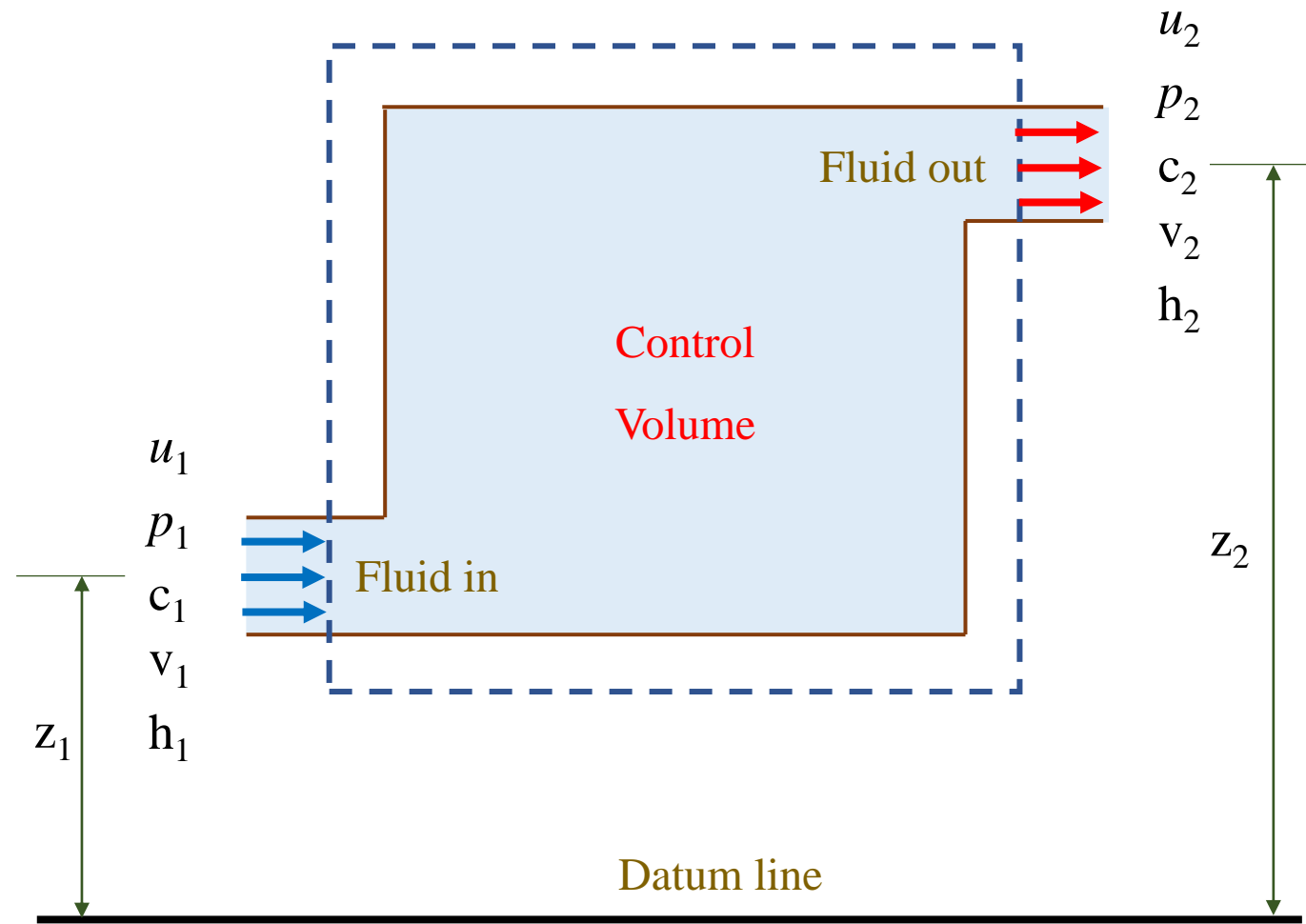
Q = Heat entering the control volume (J)

q = Heat entering the control volume per unit mass (J/kg)

W = Work transferred from the control volume (J)

w = Work transferred from the control volume per unit mass (J/kg)

Energy can neither be created nor be destroyed, but it can be transformed from one form to the other.

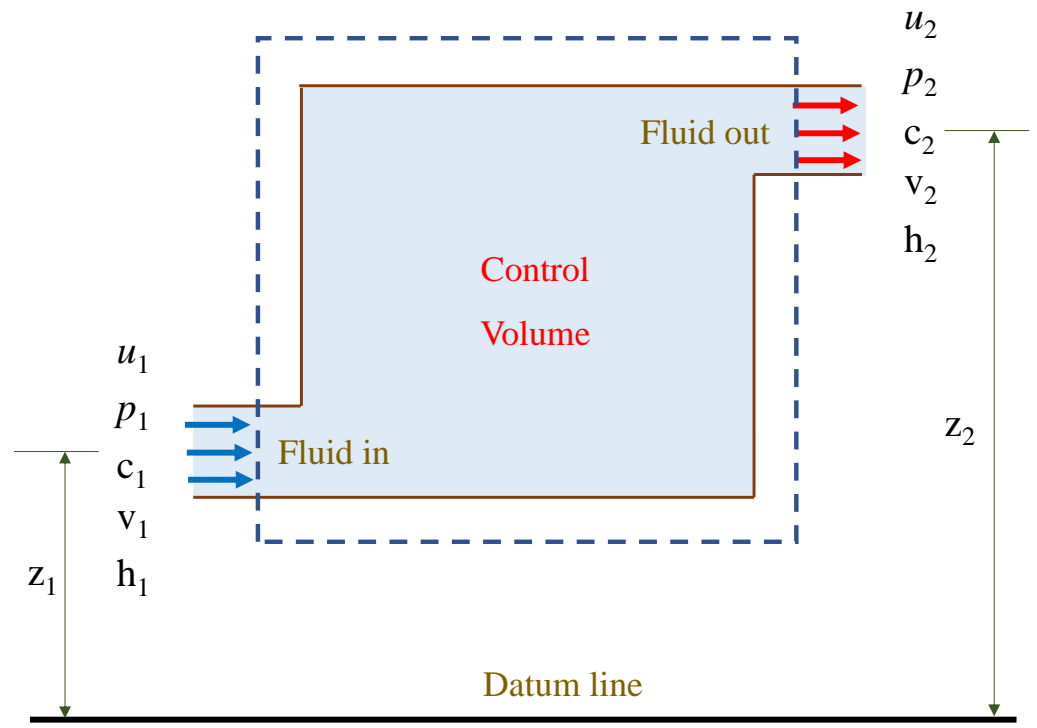


First law of thermodynamics applied for a steady flow

Energy can neither be created nor be destroyed, but it can be transformed from one form to the other.

$$\text{Energy in} + \text{Heat} = \text{Energy out} + \text{Work}$$

Internal energy	} + Heat =	Internal energy	} + Work
Flow energy		Flow energy	
Kinetic energy		Kinetic energy	
Potential energy		Potential energy	



$$m u_1 + m p_1 v_1 + \frac{1}{2} m c_1^2 + m Z_1 g + Q = m u_2 + m p_2 v_2 + \frac{1}{2} m c_2^2 + m Z_2 g + W$$

$$m \left(u_1 + p_1 v_1 + \frac{c_1^2}{2} + Z_1 g \right) + Q = m \left(u_2 + p_2 v_2 + \frac{c_2^2}{2} + Z_2 g \right) + W$$

$$u_1 + p_1 v_1 + \frac{c_1^2}{2} + Z_1 g + Q = u_2 + p_2 v_2 + \frac{c_2^2}{2} + Z_2 g + W$$

We know that $h = u + pv$

$$h_1 + \frac{c_1^2}{2} + Z_1 g + Q = h_2 + \frac{c_2^2}{2} + Z_2 g + W$$

Steady flow energy equation

Turbine

$$h_1 + \frac{c_1^2}{2} + Z_1g + Q = h_2 + \frac{c_2^2}{2} + Z_2g + W$$

A turbine is a device which has blades to produce rotational work

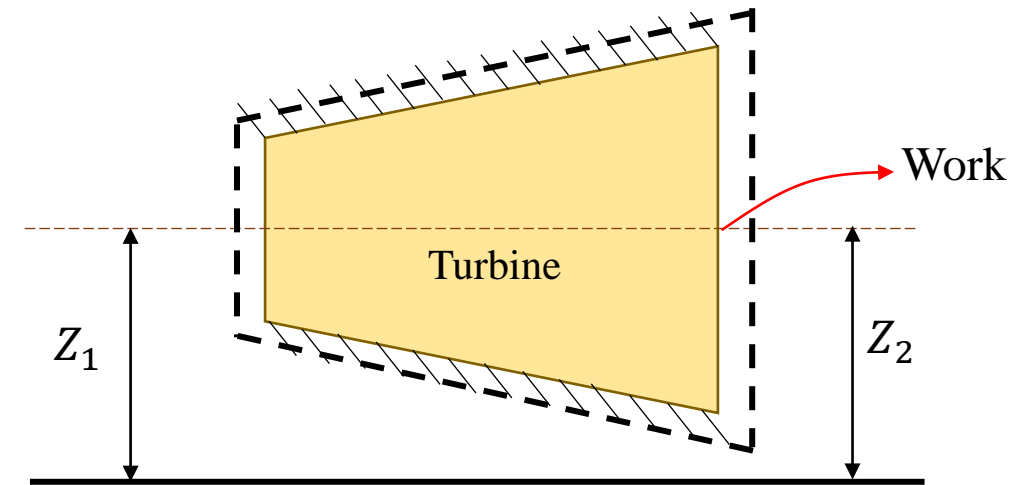
For turbine:

1. The potential energy of inlet and outlet of turbine is same
2. The velocity of inlet is almost equal to the outlet velocity
3. The turbine is well insulated at the outside. So no heat transfer occur
4. Work is done by the system which means the work is “+ve”

$$h_1 + \frac{c_1^2}{2} + Z_1g + Q = h_2 + \frac{c_2^2}{2} + Z_2g + W$$

$$h_1 = h_2 + W$$

$$W_{turbine} = h_1 - h_2$$



$$h_1 + \frac{c_1^2}{2} + Z_1 g + Q = h_2 + \frac{c_2^2}{2} + Z_2 g + W$$

For compressor:

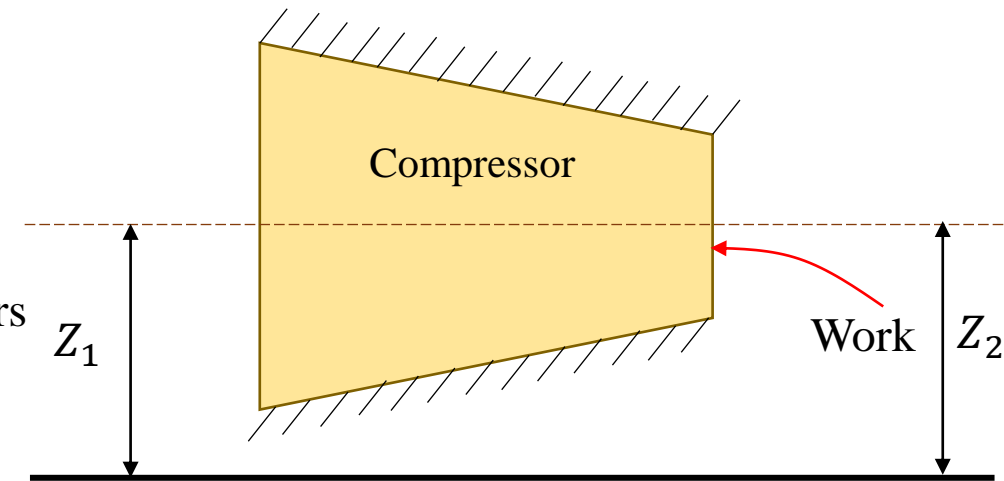
1. The potential energy of inlet and outlet of compressor is same
2. The velocity of inlet is almost equal to the outlet velocity
3. The compressor is well insulated at the outside. So no heat transfer occurs
4. Work is done to the system which means the work is “-ve”

$$h_1 + \cancel{\frac{c_1^2}{2}} + \cancel{Z_1 g} + \cancel{Q} = h_2 + \cancel{\frac{c_2^2}{2}} + \cancel{Z_2 g} - W$$

$$h_1 = h_2 - W$$

$$W_{\text{compressor}} = h_2 - h_1$$

A compressor is a device which compresses the fluid to increase its pressure, only when the energy is supplied to it.



$$h_1 + \frac{c_1^2}{2} + Z_1 g + Q = h_2 + \frac{c_2^2}{2} + Z_2 g + W$$

For nozzle:

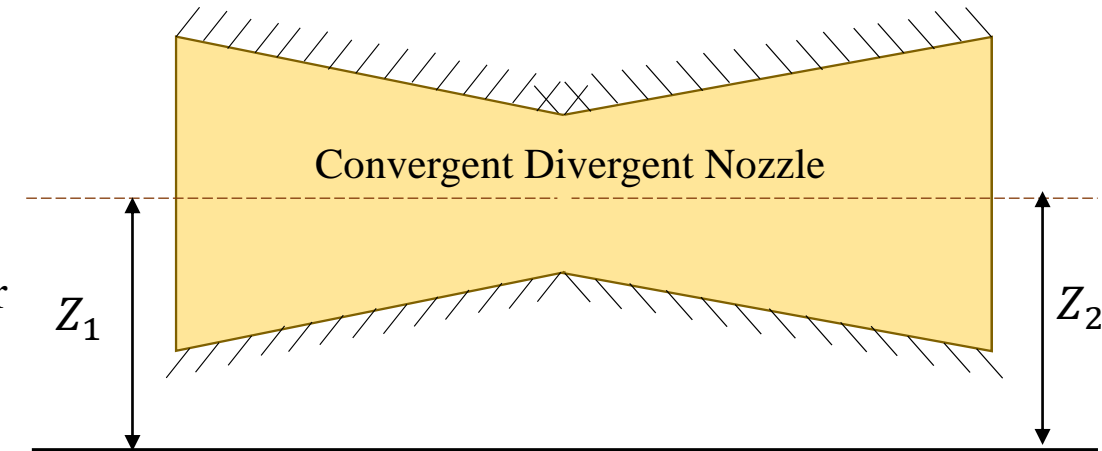
1. The potential energy of inlet and outlet of nozzle is same
2. The velocity of inlet is not equal to the outlet velocity of nozzle
3. The nozzle is well insulated at the outside. So no heat transfer occur
4. There is no work done “by” or “to” the system. So work is zero.

$$h_1 + \frac{c_1^2}{2} + \cancel{Z_1 g} + \cancel{Q} = h_2 + \frac{c_2^2}{2} + \cancel{Z_2 g} + \cancel{W}$$

$$h_1 + \frac{c_1^2}{2} = h_2 + \frac{c_2^2}{2}$$

$$c_2 = \sqrt{c_1^2 + 2(h_1 - h_2)}$$

A nozzle is a device, which increases the velocity of a fluid



Boyle's law

"The pressure of a gas increases as its volume decreases, provided the temperature remains constant."

$$P_1 V_1 = P_2 V_2$$



When you pull the plunger of a syringe back, the volume inside increases, and the pressure decreases, this causes air or liquid to be drawn into the syringe.

Charles's law

"The volume of a gas increases with an increase in temperature, provided the pressure remains constant."

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$



When air inside the hot air balloon is heated, its temperature increases, causing the air to expand (increase in volume).

Gay lussac's law

"The pressure of a gas increases as its temperature increases, provided the volume remains constant."

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$



When air inside the hot air balloon is heated, its temperature increases, causing the air to expand (increase in volume).

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

Combined gas equation