THERMODYNAMICS
FOR POLITEKNIK

EBOOK

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by

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P R E F A C E

This eBook, Fundamental Thermodynamic, is prepared as a learning resource for students pursuing Mechanical Engineering studies at Politeknik Tuanku Sultanah Bahiyah. It provides a clear explanation of thermodynamic principles, focusing on energy, heat, and work interactions within various systems. The aim is to help students understand the fundamental concepts and apply them in practical engineering contexts.

Special appreciation is extended to the Department of Mechanical Engineering for their support and guidance in producing this material. It is hoped that this eBook will serve as a useful reference for both teaching and self-learning.

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CHAPTER 1

FUNDAMENTAL CONCEPTS OF THERMODYNAMICS

What is thermodynamics?

Thermodynamics is the study of how heat, work, temperature, and energy are related to one another. In general, it focuses on how energy moves from one location to another and how it changes form. A central idea in thermodynamics is that heat is a type of energy that can be converted into a specific amount of mechanical work.

Engineers utilize thermodynamic principles to design systems that convert energy from one form to another, ensuring optimal performance.

POWER GENERATION

Designing turbines and engines that efficiently convert thermal energy into mechanical work

HVAC SYSTEMS

Developing advanced heating, ventilation, and air conditioning systems to maintain comfortable and energy - efficient indoor environments

1.1 Explain the fundamental concepts of thermodynamics.

Let's first understand what is meant by the basic concepts of thermodynamics.
The phrase **"the fundamental concepts of thermodynamics"** refers to the **basic and essential ideas or principles** that form the foundation of the science of thermodynamics.

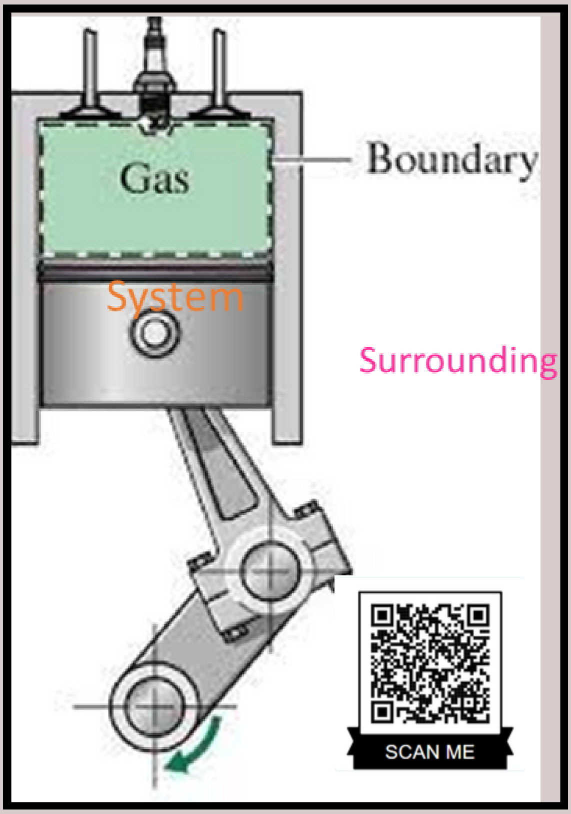
These concepts help us to understand how energy behaves, especially in the form of **heat** and **work**, and how it is **transferred**, **converted**, and **conserved**. **The fundamental concepts of thermodynamics** are the core ideas that help us understand how energy and heat behave in physical systems. Among the concepts of thermodynamics are system and surroundings, energy, heat and work, first law of thermodynamics (law of energy conservation), second law of thermodynamics, temperature and state functions.

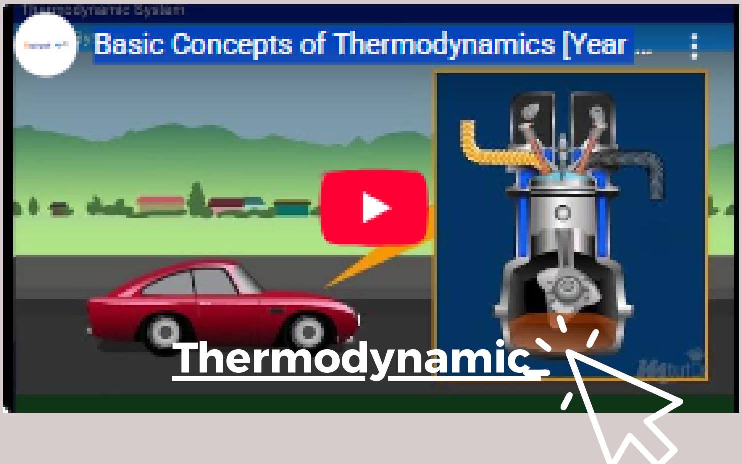
1.1.1 Principles of systems, boundary and surrounding for closed system and open system.

A **system** refers to a specific quantity of matter or a designated region in space selected for analysis.

The mass or region outside the thermodynamics system or everything external to this system is termed the **surroundings**.

The **boundary** is the real or imaginary surface that delineates the system from its surroundings. This boundary can either be fixed or movable, depending on the nature of the system under consideration.





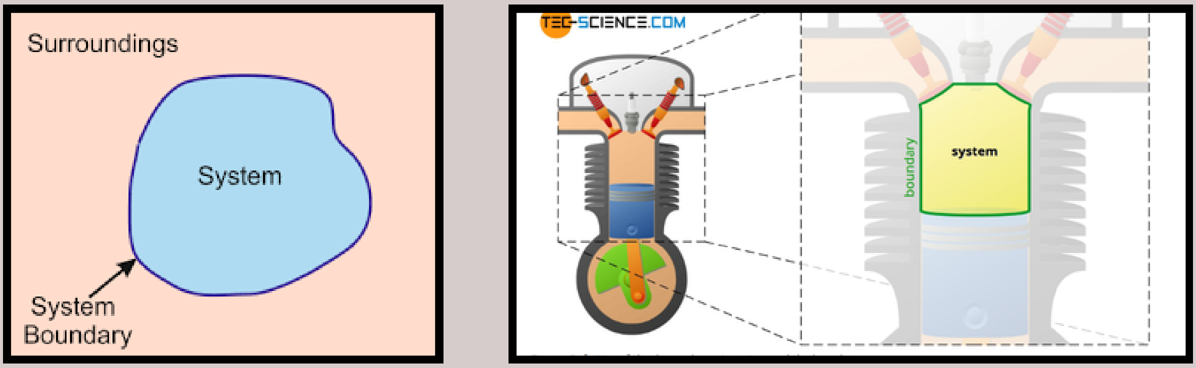


Figure 1.1: Basic concept of system,boundry and surrounding

This definition aligns with standard thermodynamic concepts, where the system is the focus of study, the surroundings encompass everything else, and the boundary defines the interface between the two .

There are three classes of systems: (a) **closed system** b) **open system and c) isolated system**, depending on the criteria used for its selection. If the system is defined by a fixed quantity of matter, it is considered a **closed system**, where mass remains constant and does not cross the system boundary. Conversely, if the system encompasses a specific region in space through which mass can flow, it is termed an **open system**, allowing both mass and energy to cross its boundaries where the energy in the form of heat and work.

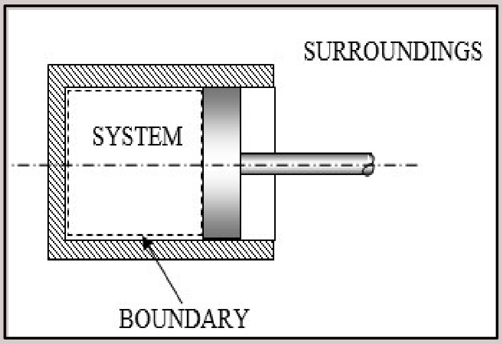


Figure 1.2: Closed system in piston

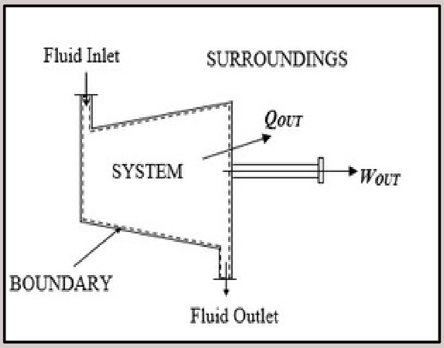
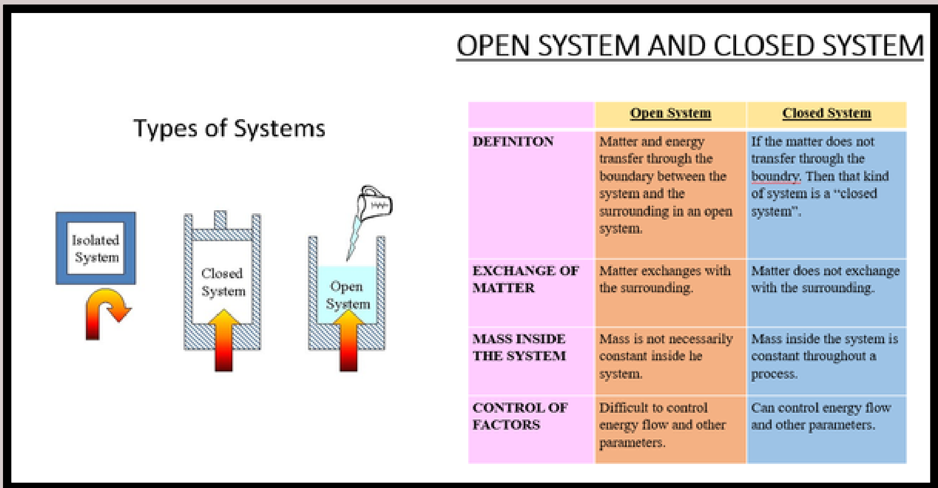


Figure 1.3: Open system in boiler

The **isolated system** is one in which there is no interaction between the system and the surroundings.It is of fixed mass and energy and there is no mass or energy transfer across the system boundary.



OPEN SYSTEM AND CLOSED SYSTEM

	Open System	Closed System
DEFINITON	Matter and energy transfer through the boundary between the system and the surrounding in an open system.	If the matter does not transfer through the boundry. Then that kind of system is a "closed system".
EXCHANGE OF MATTER	Matter exchanges with the surrounding.	Matter does not exchange with the surrounding.
MASS INSIDE THE SYSTEM	Mass is not necessarily constant inside he system.	Mass inside the system is constant throughout a process.
CONTROL OF FACTORS	Difficult to control energy flow and other parameters.	Can control energy flow and other parameters.

SCAN ME

1.1.2 Thermodynamics properties, state and equilibrium

To understand and predict how a system behaves, we need to know its properties and how they are related. A **property** is something we can measure in a system or any characteristic of a system, like mass (m), volume (v), energy (E), pressure (P), or temperature (T). Each of these has a value at a specific moment and does not depend on what happened to the system before.

In thermodynamics, properties are divided into two types: extensive and intensive.

An **extensive properties** depends on the size of the system. If you divide the system into parts, the total value is the sum of the values of all parts. Examples of extensive properties are mass, volume, and energy. These properties can change over time, especially when the system interacts with its surroundings. Thermodynamic studies often focus on tracking changes in these extensive properties.

An **intensive properties**, on the other hand, does not depend on the size of the system. These properties can vary from place to place within the system and may also change over time. Examples include pressure, temperature, and specific volume. Unlike extensive properties, they are not additive and can be different at different points in the system at the same time.

State refer to the condition of a system as described by its properties. Thermodynamics is about systems that are in a balanced state, called **equilibrium**. When a system is in equilibrium, everything inside it is stable and nothing is trying to change. There are no forces or differences pushing things to move or react. If the system is cut off from its surroundings, nothing inside it will change.

1.1.3 Path, process and cycle of a system

A **process** is any change that happens when a system moves from one stable (equilibrium) state to another. In other meaning it can be define as a transformation from one state to another state. Process in a system can divide as:

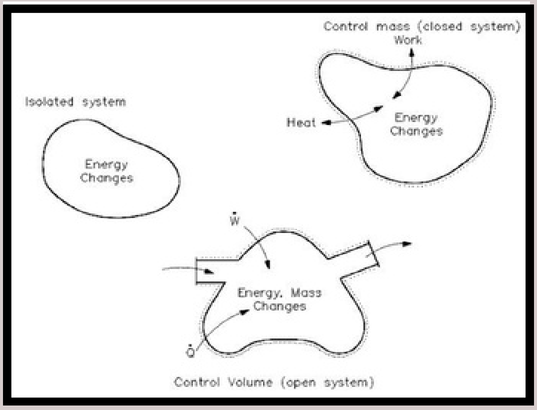
► An **isothermal process** – occurs at **constant temperature**.

► An **adiabatic process** is a process in which there is **no energy added** or subtracted from the system by heating or cooling.

► An **isentropic process** - occurs at **constant entropy**.
► An **isobaric process** – occurs at **constant pressure.**
► An **isochoric process** – occurs at **constant volume**.

The **path** of the process is the sequence of states the system goes through during this change. To fully describe a process, we need to know the starting and ending states, the path it takes, and how it interacts with its surroundings.

A thermodynamic **cycle** is a series of changes in a system where, at the end, the system returns



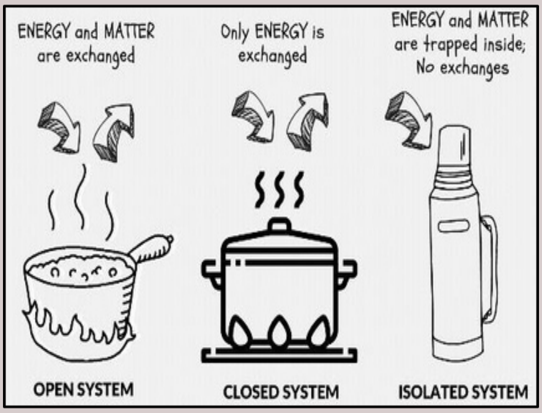
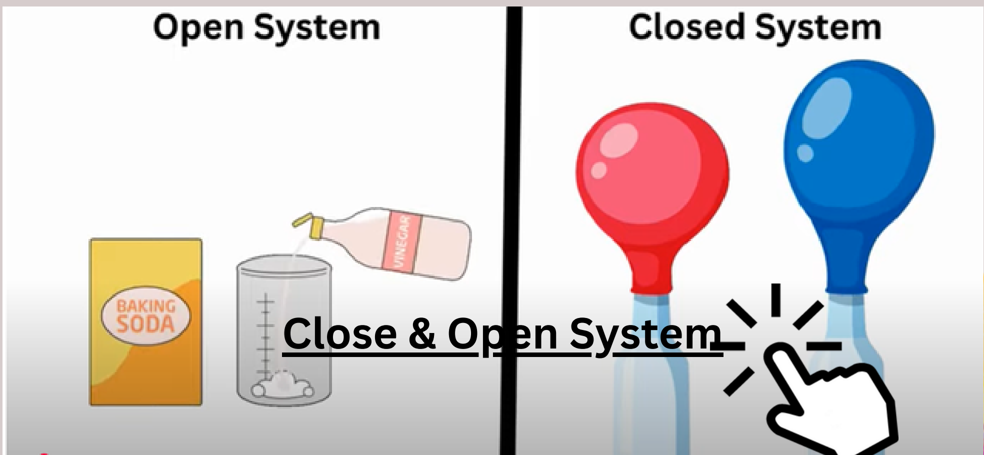


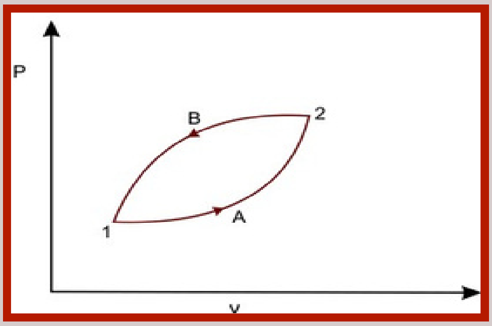
Figure 1.4 : Shows Closed System,Open System and Isolated System

This distinction is fundamental in thermodynamics, as it determines how the system interacts with its surroundings. In a closed system, energy transfer can also occur in the form of heat or work, but the mass remains unchanged. In an open system, both mass and energy can be exchanged with the environment.

Feature	Closed System	OpenSystem	Isolated System
Known as	Fixed mass system	Control volume system	Isolated system
Mass Exchange	No	Yes	No
Energy Exchange	Yes	Yes	No
Boundary	Allows energy transfer only	Allows both mass and energy transfer	No exchange of mass or energy
Example	Sealed piston-cylinder device	Boiling pot without a lid	Perfectly insulated thermos flask, the universe (theoretical example)

Table 1.1 : The differentiate of Closed System, Open System and Isolated System





Process Path
1-2-1 = A Cycle

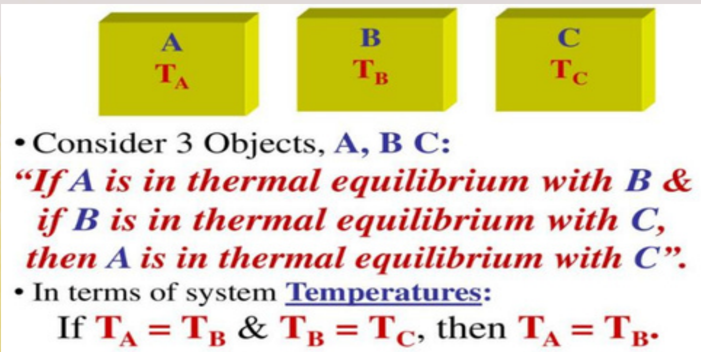
1.5 : A process between states1 to states

1.14 Zeroth`s law of thermodynamics

The Zeroth`s Law of Thermodynamics introduces the concept of temperature as a measurable property.Heat flows from a hot or high-temperature area to a cooler or lower-temperature area. When heat no longer flows, this means thermal equilibrium has been reached. At that point, the hotter system loses heat, and the cooler system gains heat. In simple terms, heat moves from high temperature to low temperature until both are the same."

It is based on the observation that if system A is in thermal equilibrium with system B - meaning there is no change in B’s properties when in contact—and system B is also in thermal equilibrium with system C, then system A must also be in thermal equilibrium with system C when they are brought into contact. This law implies that a consistent numerical value can be assigned to this shared property. If systems A, B, and C all have the same value, they will remain in thermal equilibrium with each other when in contact. This common measurable property is what we define as "temperature."

In the field of thermodynamics, temperatures are often measured using a natural or absolute scale, where zero represents the lowest possible temperature. This thermodynamic temperature is denoted by T and is typically expressed in kelvins (K), based on the Kelvin scale. Other commonly used scales include the Celsius (centigrade) and Fahrenheit scales.So it can be summarized as the following diagram for Zeroth`s law of thermodynamics.



SCAN ME

Figure 1.6 : The concept of Zeroth`s Law of Thermodynamics

1.1.5 Energy conversion

Energy Conversion: Involves the transformation of energy from one form to another within a system. Energy conversion, also known as energy transformation, refers to the process of changing energy from one form to another within a system. Examples include:

- Converting chemical energy in fuel into thermal energy during combustion.
- Transforming thermal energy into mechanical energy in a steam turbine.
- Changing mechanical energy into electrical energy in a generator.

Energy conversion processes are fundamental in various applications, such as power generation and engine operation.

Energy is the ability to perform work by applying force over a distance and exists in multiple forms. Engineering processes encompass the transformation of energy between different forms, its transfer across locations, and its storage in various forms, often involving a working substance. The unit of energy in the SI System is **Nm** or **J (Joule)**.The energy per unit mass is the specific energy,the unit of which is **J/kg.**
Energy can exist in numerous forms such as thermal, mechanical, kinetic, potential ,electric, magnetic, chemical and nuclear and their sum constitutes the total energy (E) of a system. In thermodynamic analysis, it is often helpful to consider the various forms of energy that make up the total energy of a system in two groups: macroscopic and microscopic. The macroscopic forms of energy are those a system possesses as a whole with respect to some outside reference frame such as kinetic and potential energies .The microscopic forms of energy are those related to the molecular structure of system and the degree of the molecular activity and they are independent of outside reference frames.The sum of all the microscopic forms of energy is called the internal energy of a system and is denoted by U. The energy that a system possesses as a result of its motion relative to some reference frame is called **kinetic energy** (KE).

$$KE = m\frac{C2}{2} \quad \text{(kJ)}$$

The energy that a system possesses as a result of its elevation in a gravitational field is called **potential energy** (PE) and is expressed as

$$PE = mgz$$

Internal energy is the sum of all the energies a fluid possesses and stores within itself.If we are to study thermal effects then we can no longer ignore this form of energy. We shall denote the specific (per kg) internal energy as *u* J/kg.

What is Energy

The ability to do work is termed energy; there are diverse forms of energy on this planet. Energy is
considered a measurable property in physics, which can be transferred from one object to another
to accomplish or perform work. he law of energy conservation states that "The energy can only be transformed from one form to another. It can neither be created nor be destroyed". Joule is the SI unit of energy.

Law of Conservation of Energy

One of the most fundamental laws in physics is the law of conservation of energy. The law of
conservation of energy states that the system's total energy is conserved in a closed system, that is,
asystem that is isolated from its surroundings".

Units of Energy

According to the International System of Units, energy is measured in joules. Energy is also measured in many other units which are not part of the SI, such as calories, ergs, etc.

Energy can be transferred from one object to another in the following ways:

- Through Heating – Energy can be transferred in heat using three processes: conduction,
- convection, and radiation.
- Mechanically – Energy can be transferred mechanically using the action of force.
- Electrically – Using electric power and circuits, energy can be transmitted electrically.
- Radiation – The phenomenon of radiation is used by light waves or sound waves to transmit
- energy

1.1.6 Forms of energy and energy sign convention

1.1.6.1 Forms of energy

In thermodynamics, energy manifests in various forms, broadly categorized into:

- **Kinetic Energy (KE):** Energy due to motion. For example, a moving object ossesses kinetic energy.
- **Potential Energy (PE):** Stored energy due to position or configuration, such as an object held at a height in a gravitational field.
- **Internal Energy (U):** The total microscopic energy within a system, including :

Internal Energy is the **total energy stored inside a system**. It includes:

Kinetic energy of molecules (movement)

Potential energy between molecules (bonds, forces)

Other microscopic forms (vibrations, rotation, etc.)

You **can't see or measure internal energy directly**, but you can calculate its **change** by measuring heat and work.

Type of Energy	Description	Examples
Kinetic Energy	Energy possessed by an object due to its motion.	Moving car, flowing water, spinning fan blades
Potential Energy	Stored energy due to an object's position or	Stretched spring, water at the top of a dam
Thermal (Heat) Energy	Energy related to the motion of particles within a	Boiling water, heat from a stove
Chemical Energy	Energy stored in chemical bonds between atoms and	Batteries, food, fuels like petrol
Electrical Energy	Energy caused by the movement of electric	Lightning, electric current in wires
Nuclear Energy	Energy stored in the nucleus of atoms, released during	Nuclear power plants, the Sun
Light (Radiant) Energy	Energy carried by electromagnetic waves,	Sunlight, laser beam
Sound Energy	Energy produced by vibrating objects and transmitted through a medium.	Musical instruments, speakers
Elastic Energy	Energy stored in objects that can be stretched or compressed.	Rubber bands, compressed springs
Gravitational Energy	Energy due to an object's height above the ground.	Waterfall, lifted object

1.1.6.2 Energy Sign Convention

The first law is a **statement of energy conservation**. It says: **Energy cannot be created or destroyed, only transferred or transformed.** In thermodynamics, this law is written as:

$$dU = \Delta U = Q - W$$

Where

:

dU = ΔU = Change in internal energy
Q = Heat added to the system
W = Work done *by* the system

In thermodynamics, sign conventions a rule or guideline used to decide whether the energy transfer, like heat or work, should be marked as positive or negative when it moves between a system and its surroundings.

Heat (Q): Positive when heat is added or flow into the system; **negative** when heat is
removed or flow out of a system.

Q>0 : heat done on the system = Q in

Q<0 : heat done by the system = Q out

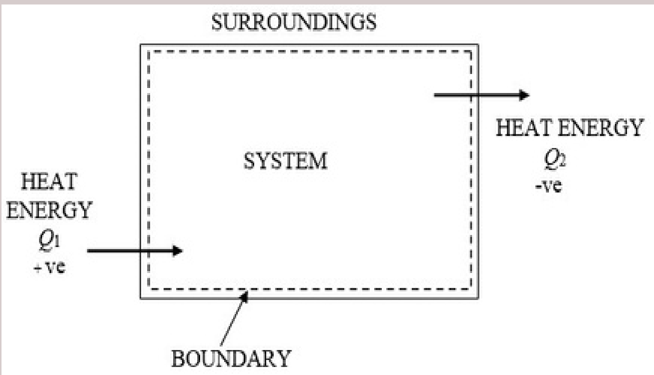


Figure 1.7 : Sign convention for heat transfer

Work (W): Positive when work is done by the system on the surroundings; **negative** when work is done on the system by the surroundings.

The unit of work is **Nm** or **Joule** where **1 Nm = 1 Joule**

The rate at which work is done by or upon the system is known as **power**.The unit of power is **J/s** or **watt**.

W>0 : work done by the system = Wout

W<0 : work done on the system = Win

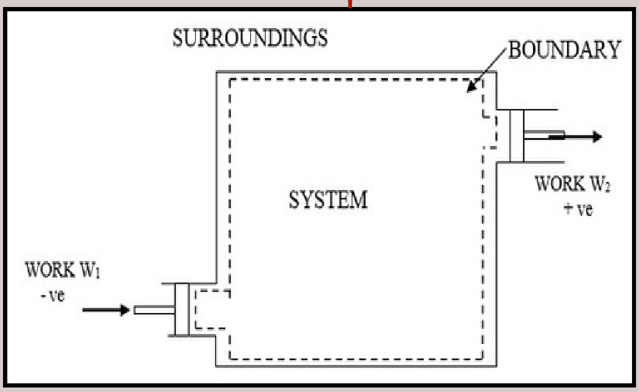


Figure 1.8 : Sign convention for work transfer

1.1.7 Energy transfer by heat and work

Heat transfer and work transfer are types of energy interactions. A closed system can exchange energy with its surroundings in two ways: through heat or through work. Thermodynamics studies how these energy exchanges cause changes in the system's properties.

• The same change in a closed system can happen either through heat transfer or work transfer. Whether it's heat or work depends on what we define as the system.

• Both heat and work happen at the system's boundary. They are not inside the system but are seen as energy crossing in or out at the boundary.

• It is incorrect to say a system "total heat" or "contains work" because heat and work are not properties of the system. A system cannot store heat or work. They are forms of energy in motion, not things that stay inside the system.

• Heat transfer only happens because of a temperature difference. Any other kind of energy exchange is called work.

• Heat and work are path functions, not state properties. This means the amount of heat or work depends on the way (or path) the system changes from one state to another, not just the start and end points.

Energy Transfer by Heat and Work | Thermodynamics |

Exercises

1. What is thermodynamics?
a) study of the relationship between heat and other forms of energy
b) study of the conversion of chemical energy to other forms of energy
c) study of the relationship between mechanical energy to other forms of energy
d) study of the conversion of mechanical energy to other forms of energy

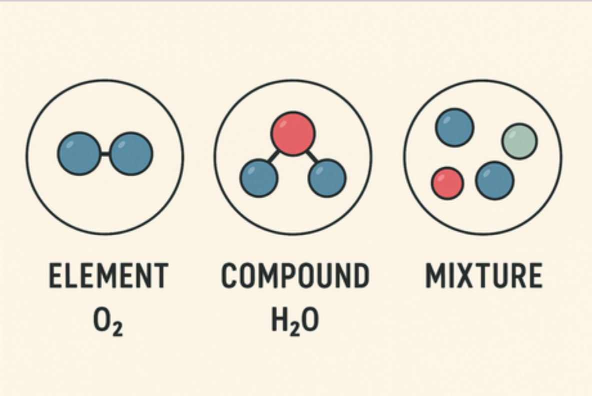
2. Which of the following is a thermodynamics law?
a) Zeroth law of thermodynamics
b) Faraday's Law of thermodynamics
c) Ideal Gas Law of thermodynamics
d) Boyle's Law of thermodynamics

3. Which of the following is an application of thermodynamics?
a) Refrigerators
b) Gas compressors
c) Power plants
d) All of the mentioned

4. Which of the following is a type of thermodynamic system?
a) Open system
b) Closed system
c) Thermally isolated system
d) All of the mentioned

2.1 EXPLAIN THE PROPERTIES OF PURE SUBSTANCES.

1.0 A pure substance is a material that has a constant composition and consistent properties throughout the sample. It contains only one type of particle — either a single element or a single compound — and cannot be separated into other substances by physical means.



SINGLE

2.0 A single element is a pure substance made up of only one type of atom. It cannot be broken down into simpler substances by chemical means. All the atoms in a single element have the same number of protons in their nuclei, which defines the element.

Example:

- Oxygen (O_2): A molecule made of two oxygen atoms. Since both atoms are of the same element (oxygen), it is still considered a single element.

Key Characteristics:

- Composed of one kind of atom
- Represented by a chemical symbol (e.g., O for oxygen, He for helium)
- Found on the periodic table
- Can exist as individual atoms (e.g., He) or molecules (e.g., O_2, N_2)

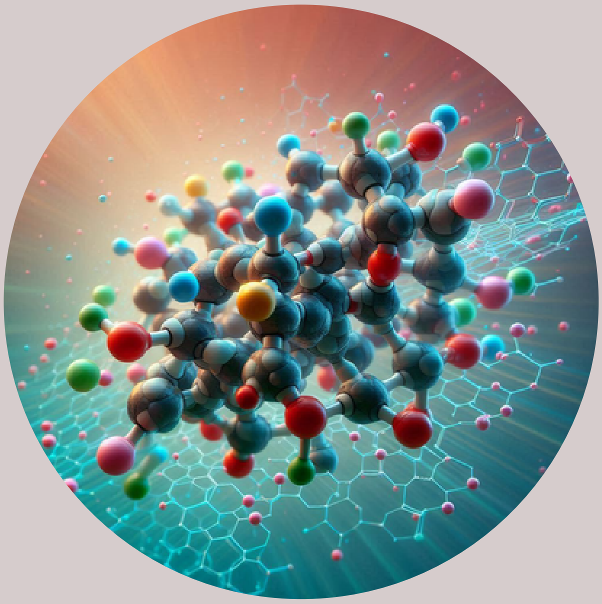
3.0 A single compound is a pure substance made up of two or more different elements that are chemically bonded together in a fixed ratio. The properties of a compound are different from the properties of the elements that form it.

Example:

- Water (H_2O): Made of two hydrogen atoms and one oxygen atom chemically bonded. It is a single compound because it's a pure substance with a consistent composition.

Key Characteristics:

- Composed of different elements in a fixed proportion
- Elements are chemically combined, not just mixed
- Has a chemical formula (e.g., H_2O, CO_2, NaCl)
- Can be broken down into its elements by chemical reactions, not physical means
- Has uniform properties throughout

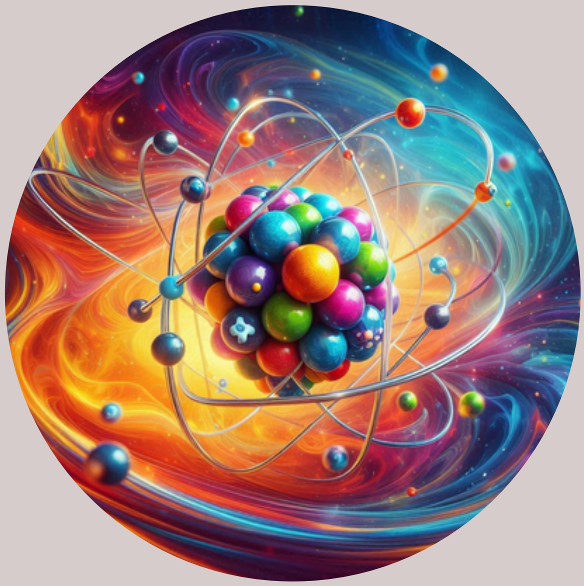


COMPOUND

4.0 A mixture is a combination of two or more substances (elements, compounds, or both) that are physically combined, not chemically bonded. The components retain their individual properties and can be separated by physical means.

Key Characteristics:

- Components are not chemically bonded
- Variable composition (no fixed ratio)
- Can be physically separated (filtration, distillation, etc.)
- Each component keeps its own chemical identity



MIXTURE

PROBLEMS 1

Q1. Which of the following is a pure substance? C1: Remembering

A. Air

B. Salt water

C. Oxygen gas (O_2)

D. Steel

Q2. A mixture is best described as: C1: Remembering

A. A substance with a fixed ratio of elements

B. A physical combination of two or more substances

C. A single element in its purest form

D. A chemically bonded compound

Q3. Which of the following is an element? C1: Remembering

A. Water

B. Carbon dioxide

C. Sodium (Na)

D. Sugar

Q4. What distinguishes a compound from a mixture? C2: Understanding

A. Compounds can be separated by physical methods

B. Mixtures always have fixed compositions

C. Compounds are chemically combined; mixtures are not

D. Mixtures contain only one kind of substance

Q5. Identify the correct classification for the following materials: C3: Applying

A: Copper wire

B: Salt water

C: Carbon dioxide

Which grouping is correct?

A. A – Element, B – Mixture, C – Compound

B. A – Mixture, B – Compound, C – Element

C. A – Compound, B – Mixture, C – Element

D. A – Element, B – Compound, C – Mixture

✅ CLO 1: DESCRIBE AND CLASSIFY PURE SUBSTANCES, ELEMENTS, COMPOUNDS, AND MIXTURES

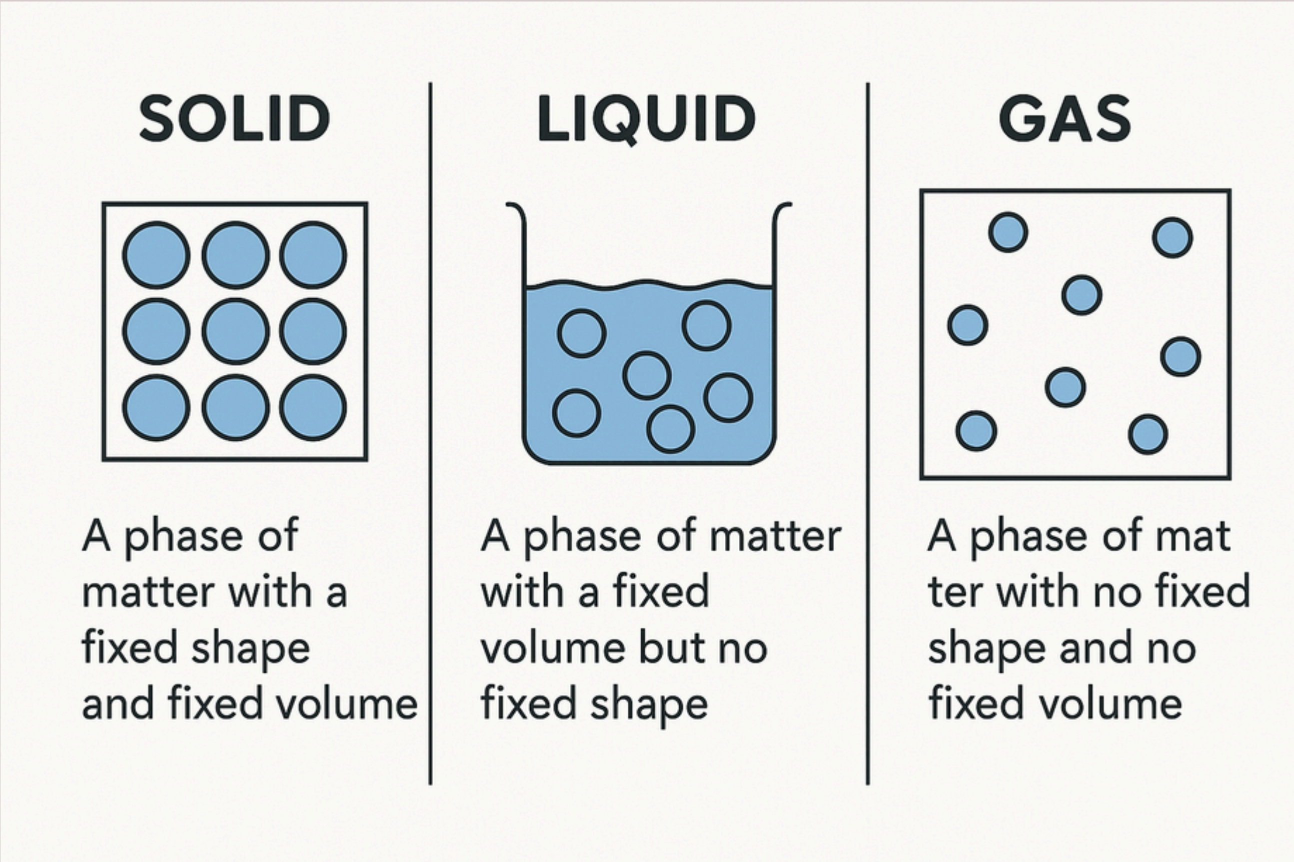
Question	Task Description	Cognitive Level	CLO 1 Objective
Q1	Identify a pure substance from a list	**C1: Remembering**	Recall basic definitions of pure substances
Q2	Recognize the definition of a mixture	**C1: Remembering**	Recall the definition and characteristics of mixtures
Q3	Identify an element from a list	**C1: Remembering**	Recall and recognize elements from other substances
Q4	Understand the difference between compound and mixture	**C2: Understanding**	Explain and differentiate based on bonding and composition
Q5	Classify real-world materials as element, compound, or mixture	**C3: Applying**	Apply conceptual understanding to classify substances

2.1.1 PHASE-CHANGE PROCESSES OF PURE SUBSTANCES

1.0 Types of phase

I. Solid (ice)
II.Liquid (water)
III. Gas (steam)

It may transition between phases without changing its chemical identity. For instance, water can exist as ice, liquid water, or steam—still H_2O in all cases.

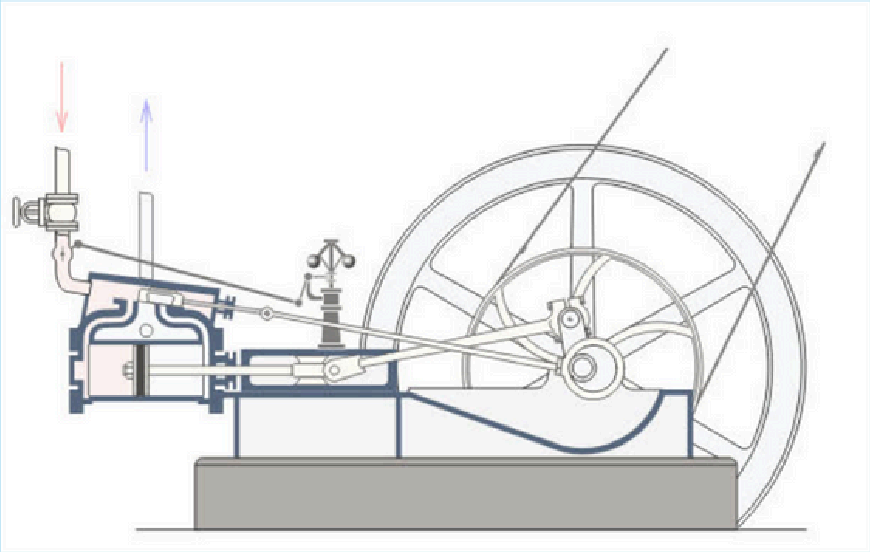


🔍 Example: Water as a Pure Substance

Water is one of the most studied pure substances in thermodynamics. When heated at constant pressure: It stays liquid up to 100°C (at 1 atm) At 100°C, it boils (liquid and vapor coexist) With more heat, it becomes superheated steam

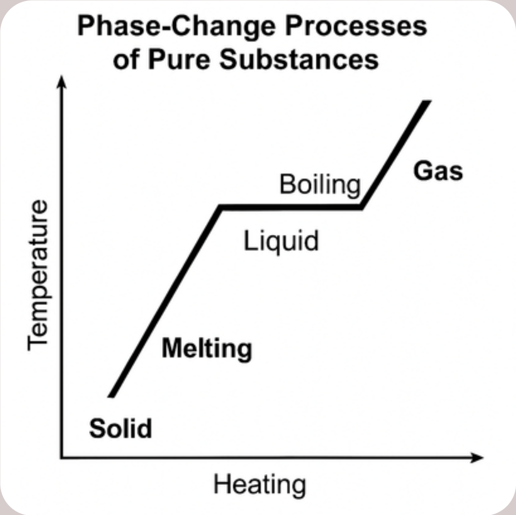
STEAM ENGINE

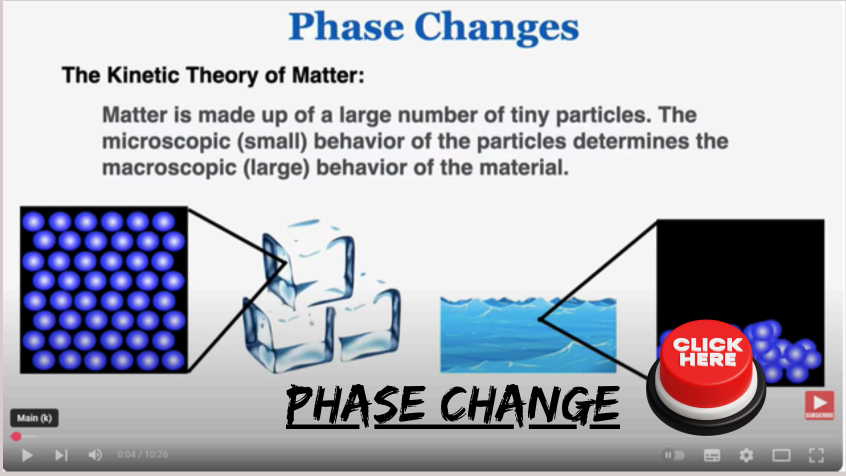
ENJIM WAP DIGUNAKAN SEBAGAI PENGERAK UTAMA BAGI STESYEN PAM, KERETA API, KAPAL WAP, ENJIN GESERAN (TRACTION ENGINE), LORI WAP DAN KENDERAAN LAIN

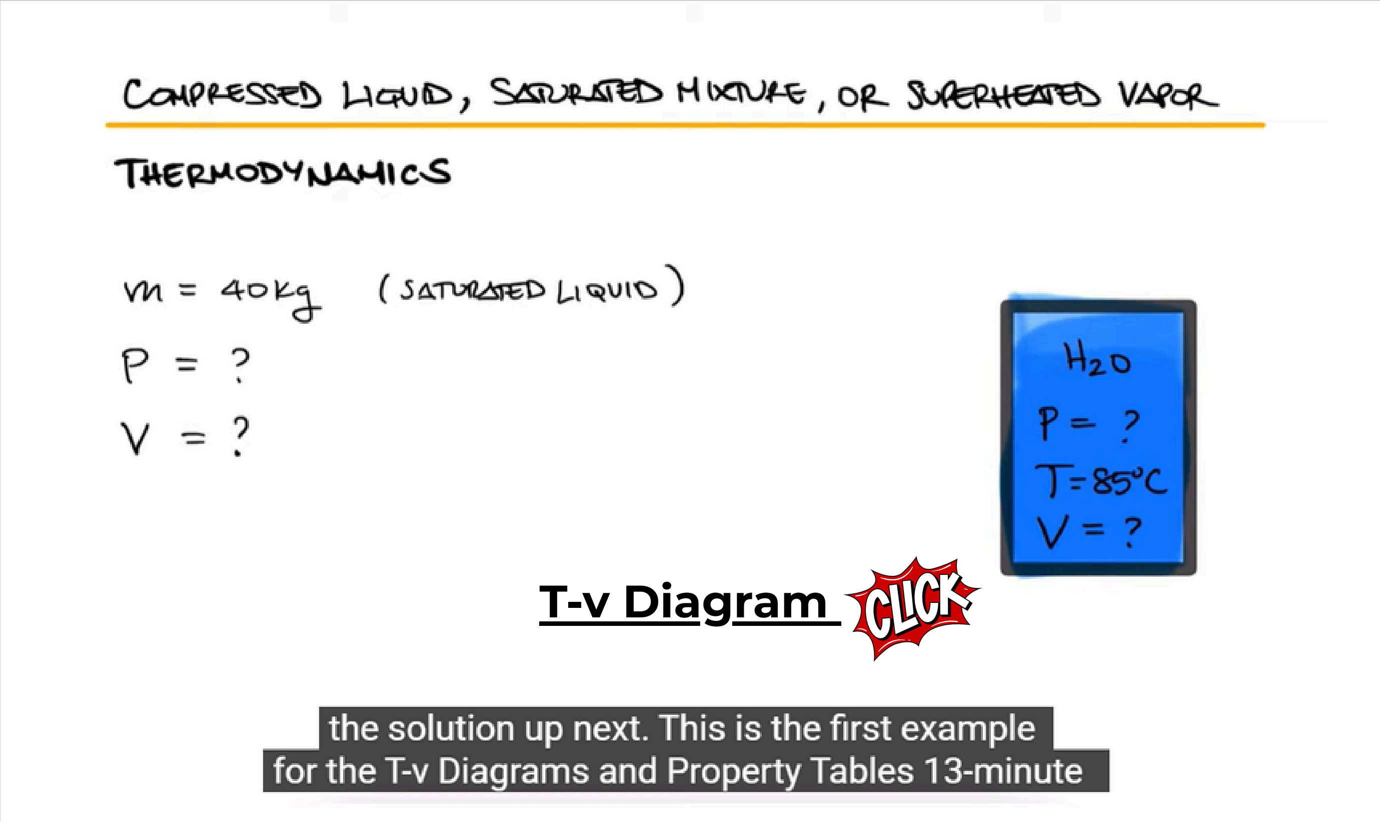


2.1.2 Phase change process

The phase change process refers to the transformation of a substance from one state of matter (phase) to another, due to changes in temperature or pressure, without changing its chemical composition.







Below are the main phase-change processes of a pure substance (like water) as temperature changes:

STATE 1	PROCESS
Solid → Liquid (Melting)	• Process: Ice melts into water. • Temperature: 0°C (at 1 atm pressure). • Energy: Absorbs heat (latent heat of fusion). • Example: Ice cube melting in your hand.
Liquid → Gas (Vaporization)	• Process: Water boils into steam. • Temperature: 100°C (at 1 atm). • Energy: Absorbs more heat (latent heat of vaporization). • Types: • Boiling: Rapid, throughout the liquid. • Evaporation: Slower, only at the surface. • Example: Boiling water in a kettle.
Gas → Liquid (Condensation)	• Process: Steam turns back into water. • Temperature: Below 100°C. • Energy: Releases heat. • Example: Water droplets forming on a cold glass.

2.1.3 PROPERTY DIAGRAMS OF PHASE-CHANGE PROCESS FOR T-V DIAGRAM AND P-V DIAGRAM

In thermodynamics, property diagrams help visualize and understand the behavior of substances during phase-change processes. Two important diagrams for this are the Temperature–Volume (T–V) and Pressure–Volume (P–V) diagrams.

2.0 PROPERTIES OF PURE SUBSTANCES

A pure substance is a substance with fixed chemical composition (e.g. water, air, ammonia,
refrigerants). It is homogeneous and uniform in composition, and can exist in different phases such
as solid, liquid, and vapor.

2.1 EXPLAIN THE PROPERTIES OF PURE SUBSTANCES

2.1.1 PHASES OF PURE SUBSTANCES

- Solid phase: molecules are closely packed, vibrate in fixed positions.
- Liquid phase: molecules are close but can move around, definite volume but no fixed shape.
- Vapor phase: molecules are far apart and move randomly, no definite volume or shape.

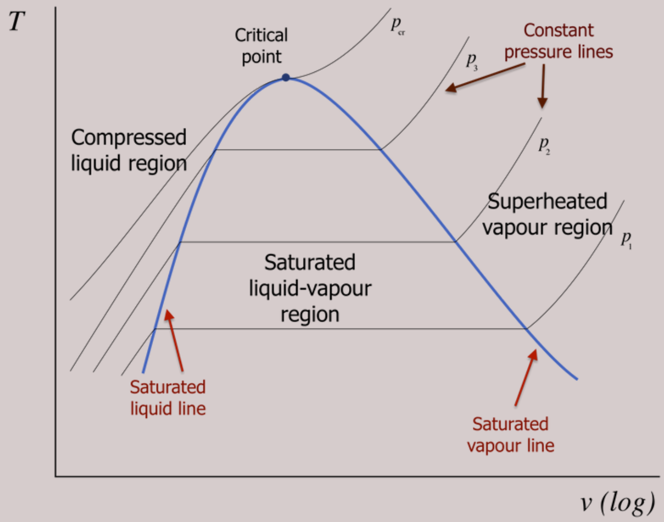
2.1.2 PHASE AND PHASE-CHANGE PROCESSES

Phase change occurs when a substance changes from one phase to another at constant pressure
and temperature:

- Solid « Liquid (melting/freezing)
- Liquid « Vapor (evaporation/condensation)
- Solid « Vapor (sublimation/deposition)

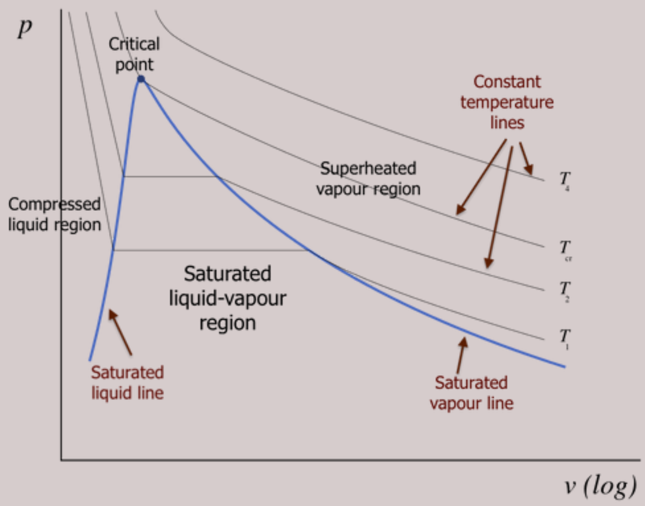
✅ 1. T–V DIAGRAM (TEMPERATURE VS. VOLUME)

A T-v diagram (Temperature vs. Volume Diagram) is a graphical representation of the thermodynamic state of a substance, plotting temperature on the y-axis and a given volume on the x-axis to understand phase transitions and the behavior of substances, for example the phase change of water.

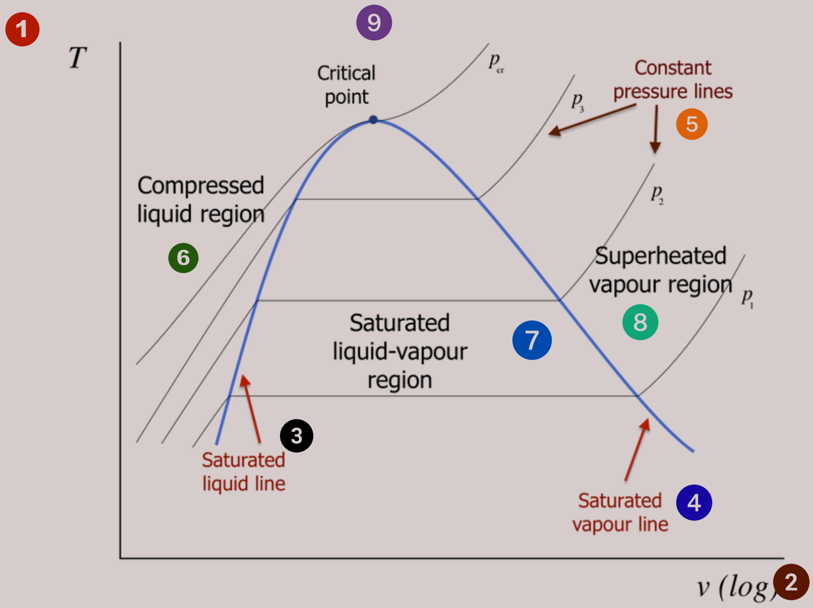


✅ 2. P–V DIAGRAM (PRESSURE VS. VOLUME)

A P-V diagram (Pressure vs. Volume Diagram) is a graph that plots pressure against volume for a system, usually a gas, undergoing a process. It is a useful tool in thermodynamics to visualize and analyze changes in state and work done during a process. The graph plots pressure on the y-axis and a given volume on the x-axis.



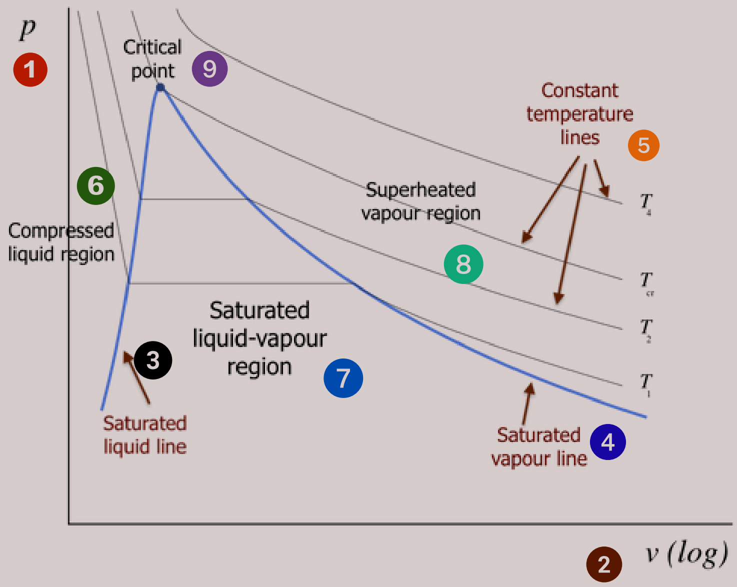
T–V DIAGRAM (TEMPERATURE VS. VOLUME)



Instructions

1. Y-axis: Temperature (T) °C
2. X-axis: Specific Volume (v) m^3/kg
3. Saturated liquid line
4. Saturater vapour line
5. Constant pressure line
6. Compressed liquid region
7. Saturated liquid -vapour region
8. Superheated vapour region
9. Critical point

P–V DIAGRAM (PRESSURE VS. VOLUME)



Instructions

1. Y-axis: Pressure (P) bar
2. X-axis: Specific Volume (v)
3. Saturated liquid line
4. Saturater vapour line
5. Constant Temperature line
6. Compressed liquid region
7. Saturated liquid -vapour region
8. Superheated vapour region
9. Critical point

Q1. Sketch a T-V diagram and a T-v diagram to illustrate the phase-change process of a pure substance such as water at constant pressure.

Q2. The diagram below shows a T-v diagram for a pure substance.

(a) Label the regions: subcooled liquid, saturated mixture, and superheated vapor.

(b) Identify the saturated liquid line, saturated vapor line, and the critical point.

(c) Explain what happens to the specific volume when a substance is heated at constant pressure from subcooled liquid to superheated vapor

✅ CLO 1: Demonstrate understanding of pure substances and their phase-change behavior

Bil	**Question**	**Cognitive Level**	**Justification**
Q1	Sketch a **T-V** and a **T-v** diagram to illustrate phase-change at constant pressure	**C2: Understanding**	Students must understand the concept and translate it into a visual form (diagram)
Q2 (a)	Label regions: subcooled liquid, saturated mixture, and superheated vapor	**C1: Remembering**	Requires recalling the correct terminology and regions on the diagram
Q2 (b)	Identify saturated liquid line, saturated vapor line, and critical point	**C1: Remembering**	Focuses on recalling specific parts of the phase diagram
Q2 (c)	Explain changes in specific volume when heated at constant pressure	**C3: Applying**	Students apply knowledge to explain real behavior of a substance under heating

2.2 APPLY THE STATE OF STEAM USING THE PROPERTIES OF PURE SUBSTANCES.

STEAM TABLE

Thermodynamic and Transport Properties of Fluids

SI Units

arranged by

G. F. C. Rogers and Y. R. Mayhew

Fifth Edition

Blackwell Publishing

SYMBOLS IN STEAM TABLE WITH QUANTITY AND UNITS

Saturated Water and Steam

p [bar]	T_s [°C]	v_g [m³/kg]	u_f [kJ/kg]	u_g	h_f [kJ/kg]	h_{fg}	h_g	s_f [kJ/kg K]	s_{fg}	s_g
0.006112	0.01	206.1	0†	2375	0*	2501	2501	0†	9.155	9.155
0.010	7.0	129.2	29	2385	29	2485	2514	0.106	8.868	8.974
0.015	13.0	87.98	55	2393	55	2470	2525	0.196	8.631	8.827
0.020	17.5	67.01	73	2399	73	2460	2533	0.261	8.462	8.723
0.025	21.1	54.26	88	2403	88	2451	2539	0.312	8.330	8.642
0.030	24.1	45.67	101	2408	101	2444	2545	0.354	8.222	8.576
0.035	26.7	39.48	112	2412	112	2438	2550	0.391	8.130	8.521
0.040	29.0	34.80	121	2415	121	2433	2554	0.422	8.051	8.473
0.045	31.0	31.14	130	2418	130	2428	2558	0.451	7.980	8.431
0.050	32.9	28.20	138	2420	138	2423	2561	0.476	7.918	8.394

Symbol	Meaning	Unit
Ts	Temperature saturation	°C (Celsius)
P	Pressure	kPa, MPa, or bar
vf	Specific volume of saturated liquid	m³/kg
vg	Specific volume of saturated vapor	m³/kg
uf	Internal energy of saturated liquid	kJ/kg
ug	Internal energy of saturated vapor	kJ/kg
ufg = ug-uf	Change in internal energy	kJ/kg
hf	Enthalpy of saturated liquid	kJ/kg
hg	Enthalpy of saturated vapor	kJ/kg
hfg = hg-hf	Change in enthalpy energy	kJ/kg
Sf	Entropy of saturated liquid	kJ/kg.K
Sg	Entropy of saturated vapor	kJ/kg.K
Sfg = Sg - Sf	Change in Entropy energy	kJ/kg.K

📘 Example: Steam Table Data at P = 20 bar

Saturated Water and Steam

P [bar]	Ts [ºC]	vg [m³/kg]	u_f [kJ/kg]	u_g [kJ/kg]	hf [kJ/kg]		$hg - h_f$ [kJ/kg]	Sg [kJ/kg]	$Sg - S_f$ [kJ/kg.K]	Sg [kJ/kg.K]
16	201.4	0.1237	857	2596	859	1935	2794	2.344	4.078	6.422
17	204.3	0.1167	870	2597	872	1923	2795	2.372	4.028	6.400
18	207.1	0.1104	883	2598	885	1912	2797	2.398	3.981	6.379
19	209.8	0.1047	895	2599	897	1901	2798	2.423	3.936	6.359
20	212.4	0.09957	907	2600	909	1890	2799	2.447	3.893	6.340
22	217.2	0.09069	928	2601	931	1870	2801	2.492	3.813	6.305
24	221.8	0.08323	949	2602	952	1850	2802	2.534	3.738	6.272
26	226.0	0.07689	969	2603	972	1831	2803	2.574	3.668	6.242
28	230.0	0.07142	988	2603	991	1812	2803	2.611	3.602	6.213
30	233.8	0.06665	1004	2603	1008	1795	2803	2.645	3.541	6.186
32	237.4	0.06246	1021	2603	1025	1778	2803	2.679	3.482	6.161
34	240.9	0.05875	1038	2603	1042	1761	2803	2.710	3.426	6.136
36	244.2	0.05544	1054	2602	1058	1744	2802	2.740	3.373	6.113
38	247.3	0.05246	1068	2602	1073	1729	2802	2.769	3.322	6.091
40	250.3	0.04977	1082	2602	1087	1714	2801	2.797	3.273	6.070

Property	Symbol	Value
Pressure	P	20 bar
Temperature	T	212.4 °C
Specific volume (liquid)	vf	0.001170 m³/kg
Specific volume (vapor)	vg	0.09963 m³/kg
Enthalpy (liquid)	hf	908.6 kJ/kg
Enthalpy (vapor)	hg	2799.5 kJ/kg
Latent heat	hfg = hg - hf	1890.9 kJ/kg
Internal energy (liquid)	uf	762.8 kJ/kg
Internal energy (vapor)	ug	2582.0 kJ/kg
Entropy (liquid)	sf	2.433 kJ/kg·K
Entropy (vapor)	sg	6.351 kJ/kg·K
Entropy of vaporization	sfg	3.918 kJ/kg·K

"STEPS TO EXTRACT THERMODYNAMIC DATA FROM THE STEAM TABLE"

Example 1 :

1. Consider steam at **20 Bar**, find the below value:
   i. Specific volume for saturated vapor line - V_g = 0.09957 m^3/kg
   ii. Specific enthalpy for saturated liquid line - h_f = 909 kJ/kg
   iii. Temperature steam at 20 bar - T_s = 212.4 °C
   iv. Sketch a graph according to your answer.

📌 **To answer questions based on the steam table at the red line (P = 20 bar), refer to the following symbols depending on what is asked:**

- If asked for specific volume of saturated vapor → use vg
- If asked for enthalpy of saturated liquid → use hf
- If asked for Saturation temperature at 20 bar → use Ts

Example Question:
What is the enthalpy of saturated vapor at 20 bar?
→ Answer: Use hg = 2799.5 kJ/kg

Example 2

2. To determine the volume, internal energy, enthalpy, and entropy at the saturated state for P = 130 bar, we refer to the saturated steam table.

🔍 At P = 130 bar (13,000 kPa), the steam table gives the following saturated properties:

Property	Symbol	Saturated Liquid (f)	Saturated Vapor (g)
Temperature	T	327.47 °C	327.47 °C
Specific Volume	vf	0.001352 m³/kg	
	vg		0.01475 m³/kg
Internal Energy	uf	1408.4 kJ/kg	
	ug		2542.6 kJ/kg
Enthalpy	hf	1463.0 kJ/kg	
	hg		2786.0 kJ/kg
Entropy	sf	3.115 kJ/kg·K	
	sg		5.430 kJ/kg·K

✅ Final Answer at P = 130 bar (Saturated State)

A. 🔹 Saturated Liquid (subscript f)

- Specific Volume (vf) = 0.001352 m³/kg
- Internal Energy (uf) = 1408.4 kJ/kg
- Enthalpy (hf) = 1463.0 kJ/kg
- Entropy (sf) = 3.115 kJ/kg·K

B. 🔹 Saturated Vapor (subscript g)

- Specific Volume (vg) = 0.01475 m³/kg
- Internal Energy (ug) = 2542.6 kJ/kg
- Enthalpy (hg) = 2786.0 kJ/kg
- Entropy (sg) = 5.430 kJ/kg·K

Example 3

3. Determine the phase, internal energy, volume and entropy for steam at 10 bar with 2790 kJ/kg of enthalpy. Plot t-v diagram

Property	Symbol	Saturated Liquid (f)	Saturated Vapor (g)
Temperature	T	179.91 °C	179.91 °C
Specific Volume	v	v_f = 0.001127 m^3/kg	v_g = 0.1944 m^3/kg
Internal Energy	u	u_f = 640.1 kJ/kg	u_g = 2582.8 kJ/kg
Enthalpy	h	h_f = 762.6 kJ/kg	h_g = 2778.1 kJ/kg
Latent Heat of Vaporization	hfg	h_{fg} = 2015.5 kJ/kg	
Entropy	s	s_f = 2.138 kJ/kg·K	s_g = 6.586 kJ/kg·K
Entropy of Vaporization	sfg	s_{fg} = 4.448 kJ/kg·K	

Here are the results for steam at 10 bar with enthalpy = 2790 kJ/kg:

🔍 **Results:**

- 🔸 **Phase: Superheated Vapor**
- 🔸 **Internal Energy (u): 2582.80 kJ/kg**
- 🔸 **Specific Volume (v): 0.19440 m^3/kg**
- 🔸 **Entropy (s): 6.586 kJ/kg·K**

Example 3

Determine the phase, internal energy, volume and entropy for steam at 10 bar with 2790 kJ/kg of enthalpy. Plot t-v diagram

Property	**Symbol**	**Saturated Liquid (f)**	**Saturated Vapor (g)**
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Latent Heat of Vaporization	hfg	hfg = 2015.5 kJ/kg	
Entropy	s	sf = 2.138 kJ/kg·K	sg = 6.586 kJ/kg·K
Entropy of Vaporization	sfg	sfg = 4.448 kJ/kg·K	

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🔍 Results:

- 🔸 Phase: Superheated Vapor
- 🔸 Internal Energy (u): 2582.80 kJ/kg
- 🔸 Specific Volume (v): 0.19440 m^3/kg
- 🔸 Entropy (s): 6.586 kJ/kg·K

PROBLEMS 1

🔹 Example 1: Saturation Properties at Given Pressure

Q: At a pressure of 30 bar, determine:

a) Saturation temperature

b) Enthalpy of saturated liquid (hf)

c) Specific volume of saturated vapor (vg)

✅ CLO: C1 – Remembering : recall data from the steam table

🔹 Example 2: Mixture Quality Calculation

Q: A steam mixture at P = 20 bar has a specific enthalpy of 1500 kJ/kg.

Determine the quality (x) of the mixture.

✅ CLO: C3 – Applying to apply formulas and data to find steam quality (x)

🔹 Example 3: Internal Energy from Steam Table

Q: Find the internal energy (u) of saturated vapor at P = 10 bar.

✅ CLO: C1 – Remembering - extract data directly from the table

🔹 Example 4: Use of Superheated Steam Table

Q**: Find the enthalpy (h) and specific volume (v) of superheated steam at P = 10 bar and T = 400°C.**

✅ CLO: C3 – Applying understanding of how to read values under non-saturated conditions

🔹 Example 5: Determine Phase of Water

Q: At P = 1 MPa and T = 150°C, determine the phase of the substance. Is it compressed liquid, saturated, or superheated?

✅ CLO: C2 – Understanding

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