ENG 3165 LECTURE 2

THERMODYNAMICS COMPONENT

Fundamental Concepts of Thermodynamics

Introduction

- This introductory Lecture provides a basic meaning for **Classical Thermodynamics** as applied in Engineering. It further introduces the student to various important thermodynamic concepts and definitions.

WHAT IS THERMODYNAMICS?

- The word **THERMODYNAMICS** is of Latin origin and arises from the words:

Thermodynamics: therme + dynamis

- **Therme** = heat
- **Dynamis** = force/study of matter in motion

- The formal study of thermodynamics began in the early **nineteenth century** through consideration of the **motive power of heat**: the capacity of hot bodies to produce work. Today the scope is larger, dealing generally with energy and with relationships among the properties of matter.

WHAT IS THERMODYNAMICS?

Thermodynamics is a branch of science which deals with **energy transfer** and **its effects on properties** (physical and chemical) of the substance. It involves the relations between properties of a substance and the quantities of work and heat which cause a change of state or temperature.

MICROSCOPIC AND MACROSCOPIC APPROACHES TO THERMODYNAMICS

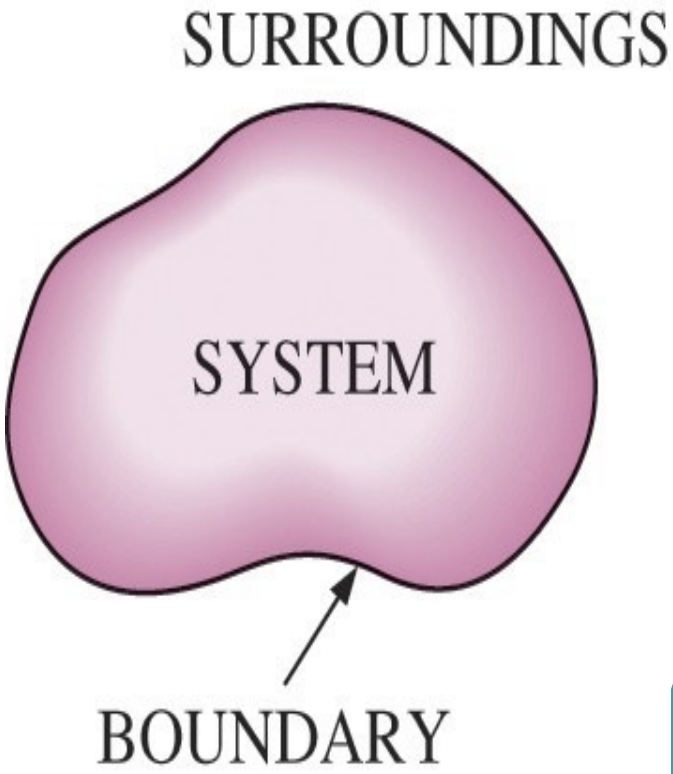
- The macroscopic approach is concerned with the gross or overall behaviour of matter. No model of the structure of matter at the molecular, atomic, and subatomic levels is directly used. Although the behaviour of systems is affected by molecular structure, the macroscopic approach allows important aspects of system behaviour to be evaluated from observations of the overall system.
- The microscopic approach is concerned directly with the structure of matter. The objective is to characterize by statistical means the average behaviour of the particles making up a system of interest and relate this information to the observed macroscopic behaviour of the system.
- For the great majority of thermal systems applications, the macroscopic approach not only provides a more direct means for analysis and design but also requires far fewer mathematical complications. For these reasons the macroscopic approach is the one adopted

MICROSCOPIC AND MACROSCOPIC VIEW OF THERMODYNAMICS

Macroscopic	Microscopic
Study of properties such as pressure, volume, temperature – usually used by engineers in thermodynamics	Study of the behaviour of individual atoms and molecules of a substance.
A few properties are required to describe the system such as P,V ,T etc. and these can be perceived by senses and measured by available instruments. Example Expansion of gases in a I.C. engine	Large no. of variables are required to describe the system such as position, KE, Velocity, P,V, T etc. It is very difficult to measure these quantities with help of available instruments.
Requires Simple mathematical formulae to analyse the system	Requires Advanced statistical and mathematical formulae to analyse the system
Known as classical thermodynamics	Known as statistical thermodynamics

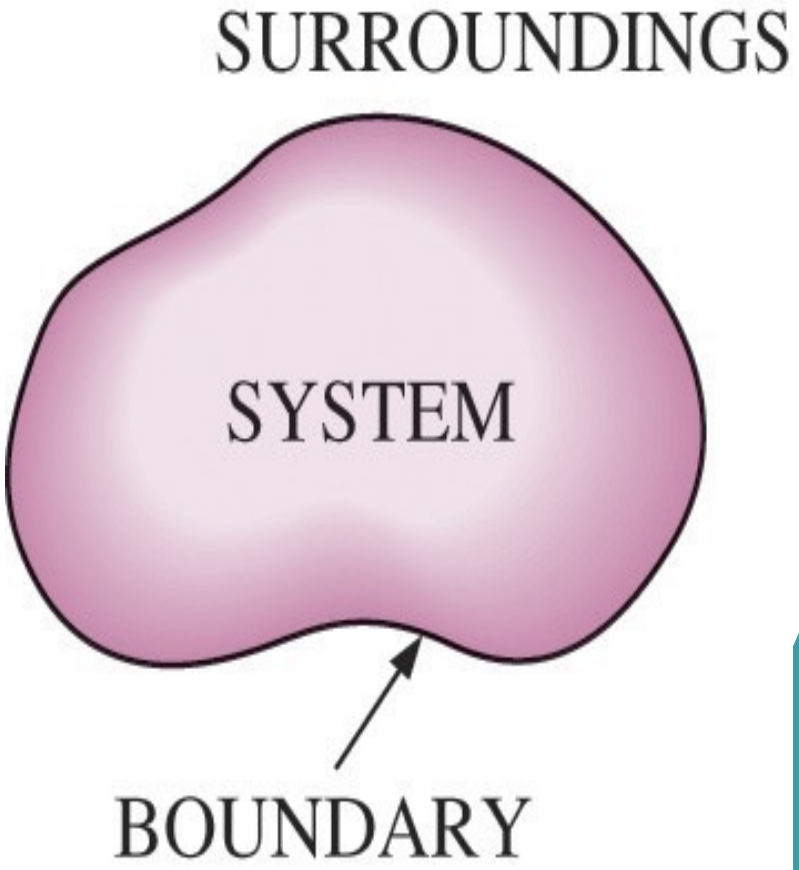
DEFINING A SYSTEM

- In thermal systems engineering, the term system is used to identify the subject of the analysis.
- Once the system is defined and the relevant interactions with other systems are identified, one or more physical laws or relations are applied.
- The system is whatever we want to study. It may be as simple as a free body or as complex as an entire chemical refinery or a power plant.
- The shape or volume of the system being analysed is not necessarily constant, as when a gas in a cylinder is compressed by a piston or a balloon is inflated.
- Everything external to the system is considered to be part of the system's surroundings.
- The system is distinguished from its surroundings by a specified boundary, which may be at rest or in motion.



DEFINING A SYSTEM

- **System**: It is a fixed mass or region in a space (control volume) where our study is focused
- **Surroundings**: The mass or region outside the system or everything external to the system
- **Boundary**: The real or imaginary surface that separates the system from its surroundings.



TYPES OF SYSTEM

- **Isolated system** – neither mass nor energy can cross the selected boundary.

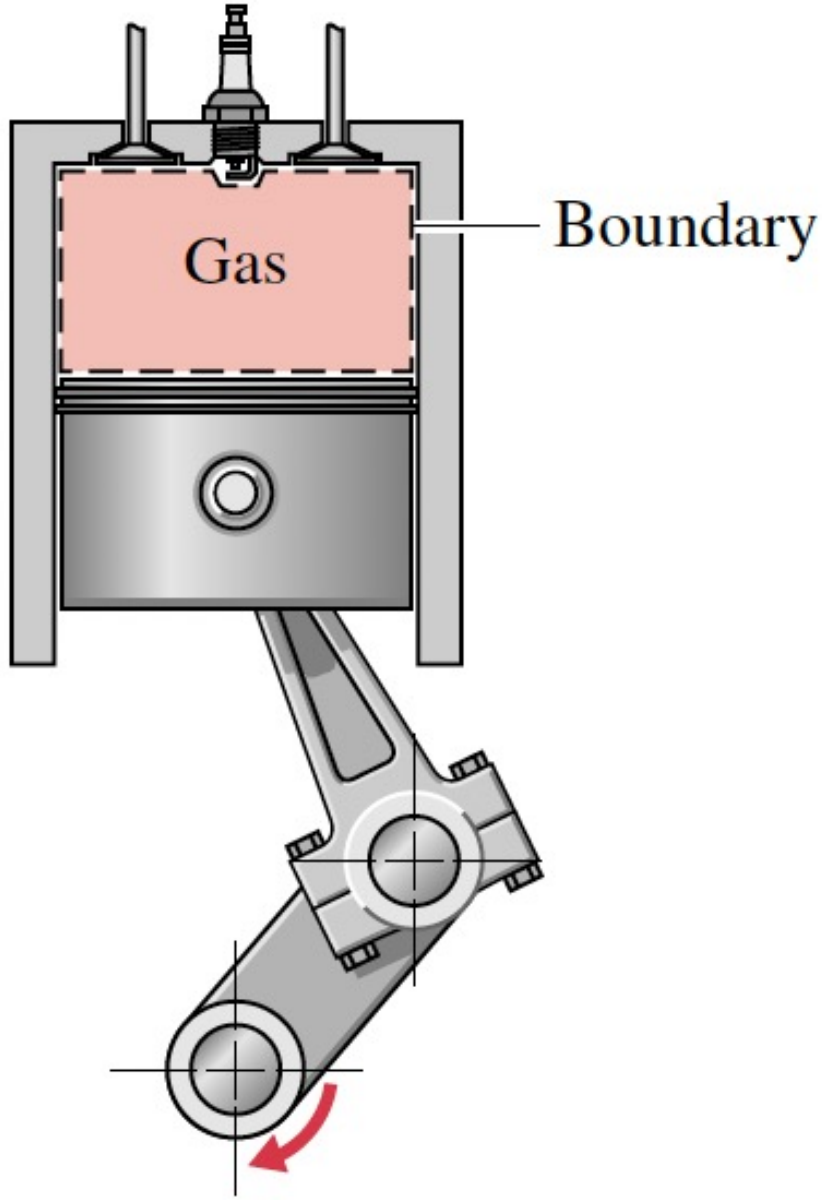
Eg. Well insulated thermos flask

- **Closed system** – only energy can cross the selected boundary

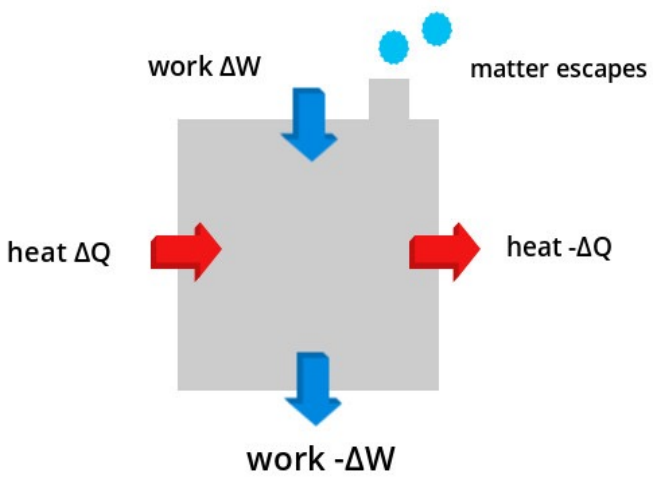
Eg. Piston-cylinder arrangement without valves

- **Open system** – both mass and energy can cross the selected boundary

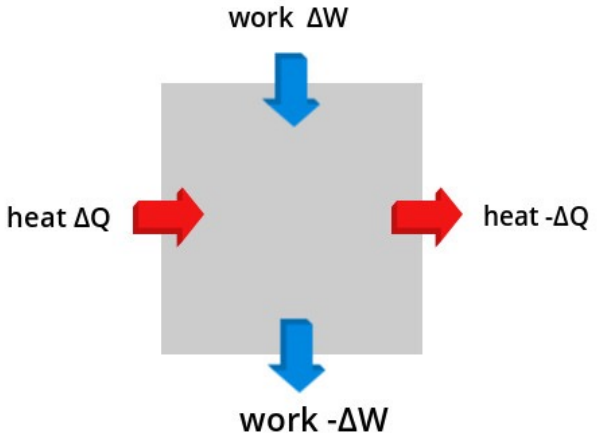
Eg. Piston-cylinder arrangement with valves



TYPES OF SYSTEM

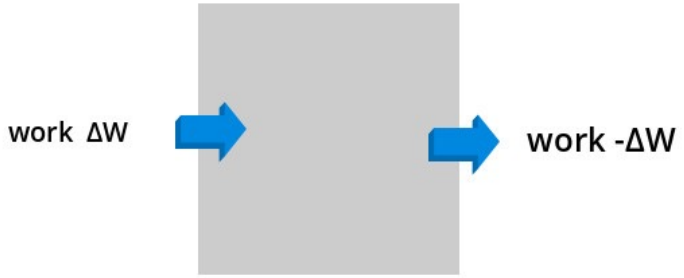


OPEN SYSTEM



CLOSED SYSTEM

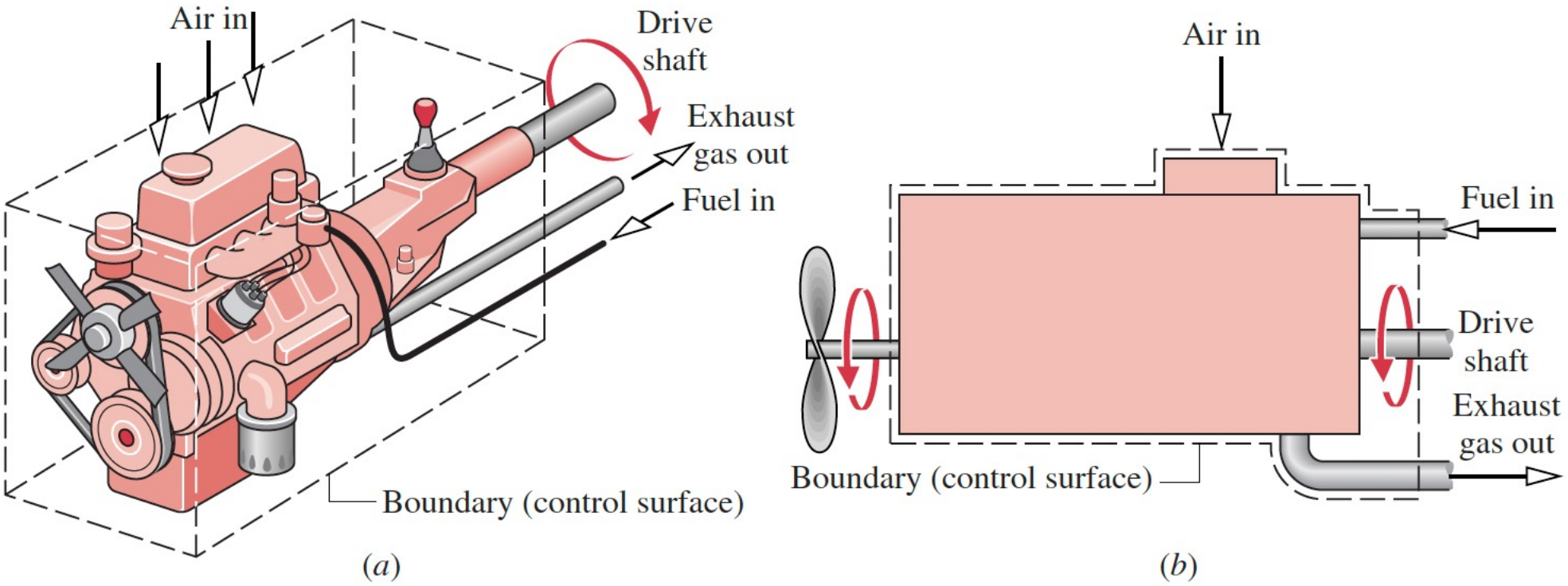
ISOLATED SYSTEM



ADIABATIC SYSTEM

TYPES OF SYSTEM

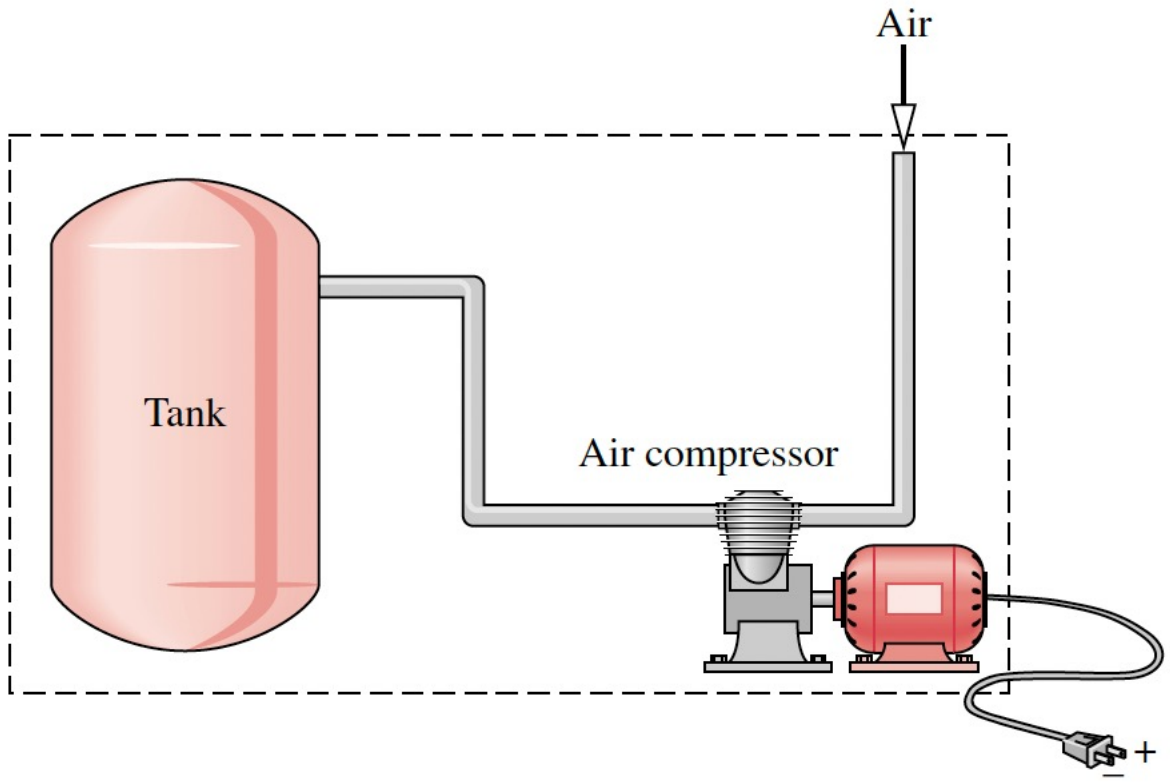
- **Isolated system** valves



Example of a control volume (open system): An automobile engine.

TYPES OF SYSTEM

- **Isolated system** valves



Air compressor and storage tank.

DEFINING A SYSTEM

- Analysis can be conducted by studying a particular quantity of matter, **a closed system**, as it passes through the device.
- It is sometimes simpler to think instead in terms of a given region of space through which mass flows. With this approach, a region within a prescribed boundary is studied.
- The region is called a **control volume.** Mass may cross the boundary of a control volume.
- A diagram of an engine is shown in the figure. The dashed line defines a control volume that surrounds the engine. Observe that air, fuel, and exhaust gases cross the boundary.
- The term control mass is sometimes used in place of closed system, and the term open system is used interchangeably with control volume. When the terms control mass and control volume are used, the system boundary is often referred to as a control surface.

PROPERTIES OF A SYSTEM

- To describe a system and predict its behavior requires knowledge of its properties and how those properties are related.
- A property of a substance is any macroscopic characteristic that can be measured or observed e.g. pressure, volume or temperature. Properties may be intensive or extensive.
- Thermodynamics also deals with quantities that are not properties, such as mass flow rates and energy transfers by work and heat
- **Intensive or Intrinsic –** Are independent of the amount of mass: e.g: Temperature, Pressure, and Density, All specific properties
- **Extensive or Extrinsic** – Varies directly with the mass (mass dependent properties) e.g: mass, volume, energy, enthalpy

PROPERTIES OF A SYSTEM

- The **STATE** of a substance is known when various thermostatic properties of a substance are known. E.g. Gas at 50ºC, atmospheric pressure, volume $1m^3$
- When any of the properties of a system change, the state changes and the system is said to have undergone a process. A **PROCESS** is a transformation from one state to another. However, if a system exhibits the same values of its properties at two different times, it is in the same state at these times.
- **PROCESS PATH** refers the infinite states through which the system passes while going from initial state to final state.
- A system is said to be at **steady state** if none of its properties changes with time.

PROPERTIES OF A SYSTEM

- Three intensive properties that are particularly important in thermal systems engineering are **specific volume, pressure, and temperature**.
- The specific **volume** $\boldsymbol{\nu}$ is defined as the **reciprocal of the density**, $\boldsymbol{\rho}$. It is the volume per unit mass. Like density, specific volume is an intensive property and may vary from point to point.
- SI units for **density** and **specific volume** are **kg/m^3** and **m^3/kg**, respectively.
- In certain applications it is convenient to express properties such as a specific volume on a molar basis rather than on a mass basis. The amount of a substance can be given on a molar basis in terms of the kilomole (kmol).

$$\boldsymbol{n = \frac{m}{M}}$$

- $The\ number\ of\ kilomoles\ of\ a\ substance,\ n,\ is\ obtained\ by\ dividing\ the\ mass,\ m,\ in\ kilograms\ by\ the\ molecular\ weight,\ M,\ in\ kg/kmol.$

VOLUME

- Volume refers to the amount of space occupied by mass and is accociated with cubic measurements.
- The SI unit of volume is the **m^3**
- Volume is also measured in litres (L)

TEMPERATURE

- Temperature describes the degree of hotness or coldness of a substance.
- The customary accepted scale for use with SI units is the **Celsius scale** with units **Degree Celsius**, ^{o}C .
- The Celsius scale is only a part of the more extensive thermodynamic scale where a temperature of absolute zero has been demonstrated.
- The absolute thermodynamic scale is called the Kelvin Scale. The Kelvin unit of temperature is called the kelvin, K.
- The kelvin has the same magnitude as the celsius degree.
- **0 ^{o}C = 273.15K,** Where -273.15K is known as absolute zero.

THERMOMETERS

- Any body with at least one measurable property that changes as its temperature changes can be used as a thermometer.
- Such a property is called a thermometric property. The particular substance that exhibits changes in the thermometric property is known as a thermometric substance.
- A familiar device for temperature measurement is the liquid-in-glass thermometer pictured which consists of a glass capillary tube connected to a bulb filled with a liquid such as alcohol and sealed at the other end.
- Other common sensors include thermocouples and Electrical-resistance sensors. Devices using conductors are known as resistance temperature detectors, and semiconductor types are called thermistors. A variety of instruments measure temperature by sensing radiation. They are known by terms such as radiation thermometers and optical pyrometers.

PRESSURE

- Pressure is defined as force per unit area. Thus if a force F is applied to an area A, and evenly distributed over the given area, then:

$$\mathbf{P} = \frac{\boldsymbol{F}}{\boldsymbol{A}}$$

- The unit for pressure is thus newton per square metre **(N/m^2).** This basic unit of pressure is sometimes called the **Pascal (Pa).**

- A commonly used multiple is the **mega-newton/metre squared = 1 MN/m^2 = 10^6 N/m^2**

- The bar may also be used**. 1 bar = 10^5 N/m^2**

- **One standard atmosphere** = **1.01325 bar** = **101,325 N/m^2**

PHASE

- The term **PHASE** refers to a quantity of matter that is homogeneous throughout in both chemical composition and physical structure. Homogeneity in physical structure means that the matter is all solid, or all liquid, or all vapor (or equivalently all gas).
- A system can contain one or more phases. For example, a system of liquid water and water vapor (steam) contains two phases. When more than one phase is present, the phases are separated by phase boundaries.
- Note that gases, say oxygen and nitrogen, can be mixed in any proportion to form a single gas phase. Certain liquids, such as alcohol and water, can be mixed to form a single liquid phase. But liquids such as oil and water, which are not miscible, form two liquid phases.

PURE SUBSTANCE

- A **PURE SUBSTANCE** is one that is uniform and invariable in chemical composition. A pure substance can exist in more than one phase, but its chemical composition must be the same in each phase.
- For example, if liquid water and water vapor form a system with two phases, the system can be regarded as a pure substance because each phase has the same composition.
- A uniform mixture of gases can be regarded as a pure substance provided it remains a gas and does not react chemically. Changes in composition due to chemical reaction are

THE TWO PROPERTY RULE

- If two independent properties of a pure substance are defined, then all other properties, or the state of the substance, are also defined.
- If the state of the substance is known then the phase or mixture of phases of the substance are also known.

CLASSIFICATION OF PROCESSES

QUASI-STATIC AND NON QUASI-STATIC

QUASISTATIC Process

- It is a kind of process that occurs infinitely slow
- It is represented by joined lines on a property diagram

NON QUASI-STATIC PROCESS

- It is the kind of process that does not occur infinitely slow
- It is represented by dashed lines on a property diagram

CLASSIFICATION OF PROCESSES

REVERSIBLE AND IRREVERSIBLE PROCESSES

REVERSIBLE PROCESS

- It is that kind of process which can be reversed in direction following the same path and without leaving any effect on the system and surrounding

IRREVERSIBLE PROCESS

- It is that kind of process which is not reversible

SOME KEY POINTS

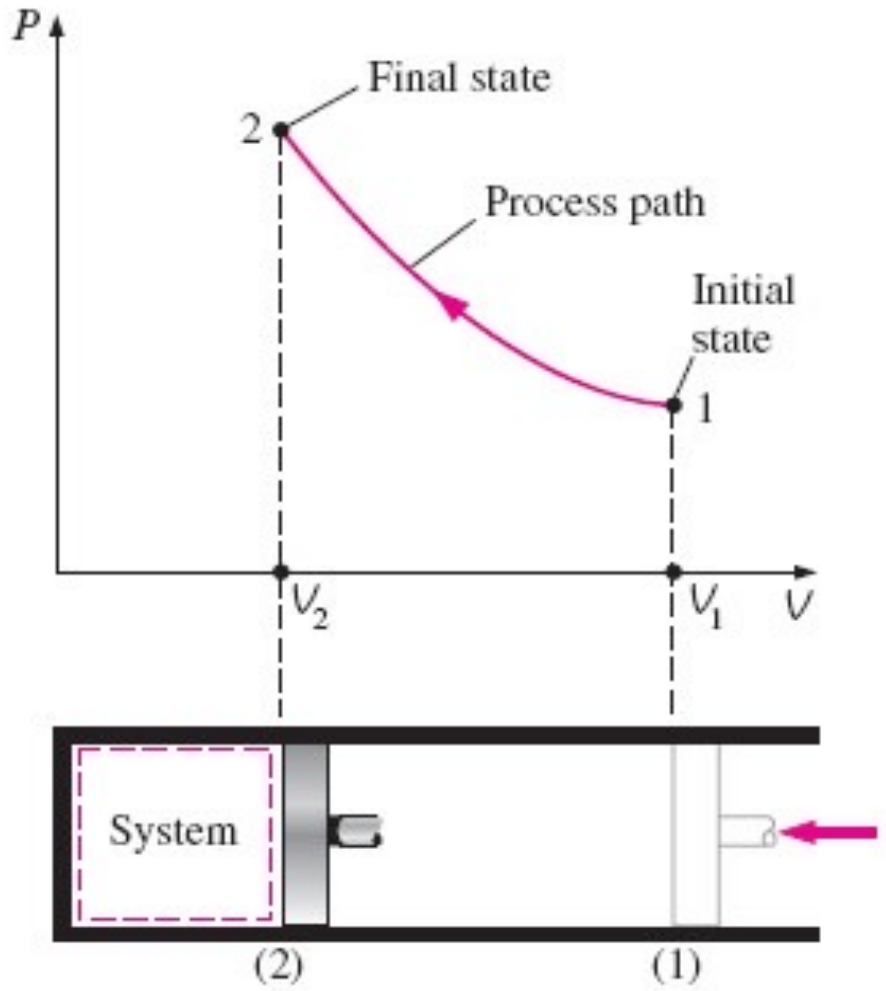
- Not all quasi-static processes are non reversible but a reversible process is always quasi-static
- quasi-static compression and expansion of a gas is a reversible process

THERMODYNAMIC CYCLES

- A thermodynamic cycle is a sequence of processes that begins and ends at the same state. At the conclusion of a cycle all properties have the same values they had at the beginning.
- Consequently, over the cycle the system experiences no net change of state.
- Cycles that are repeated periodically play prominent roles in many areas of application. For example, steam circulating through an electrical power plant executes a cycle.

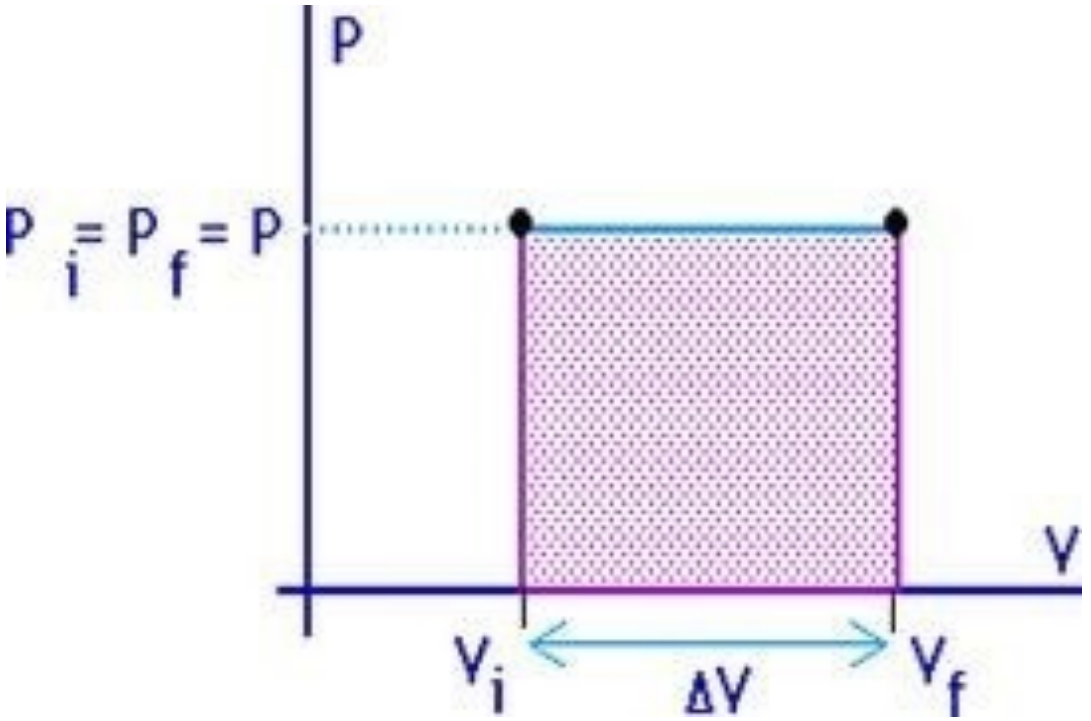
TYPES OF PROCESSES

PROCESS	PROPERTY HELD CONSTANT
Isobaric Process	Pressure
Isothermal Process	Temperature
Isochoric Process	Volume



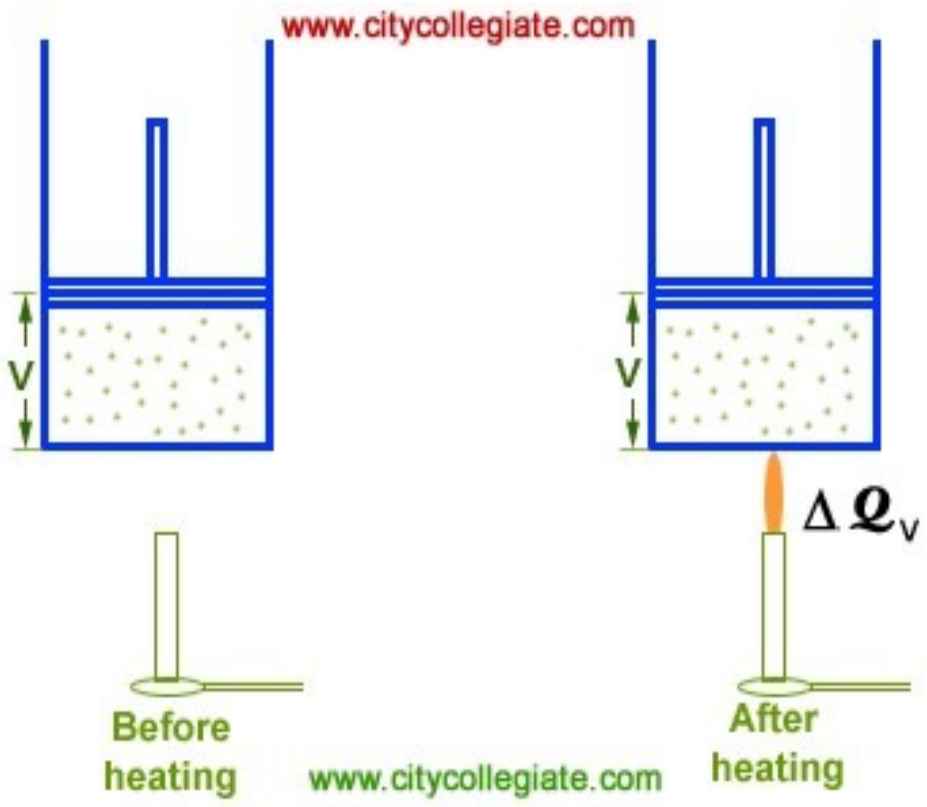
TYPES OF PROCESSES

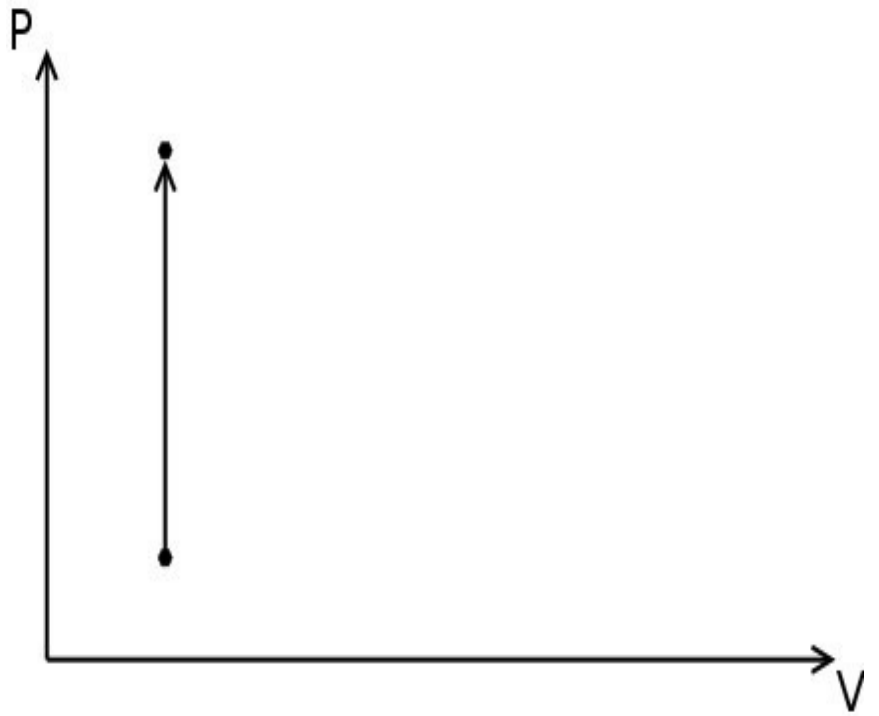
- **Isobaric process**: A process during which the pressure *P* remains constant.
- **Pressure** is Constant (**ΔP = 0**)



TYPES OF PROCESSES

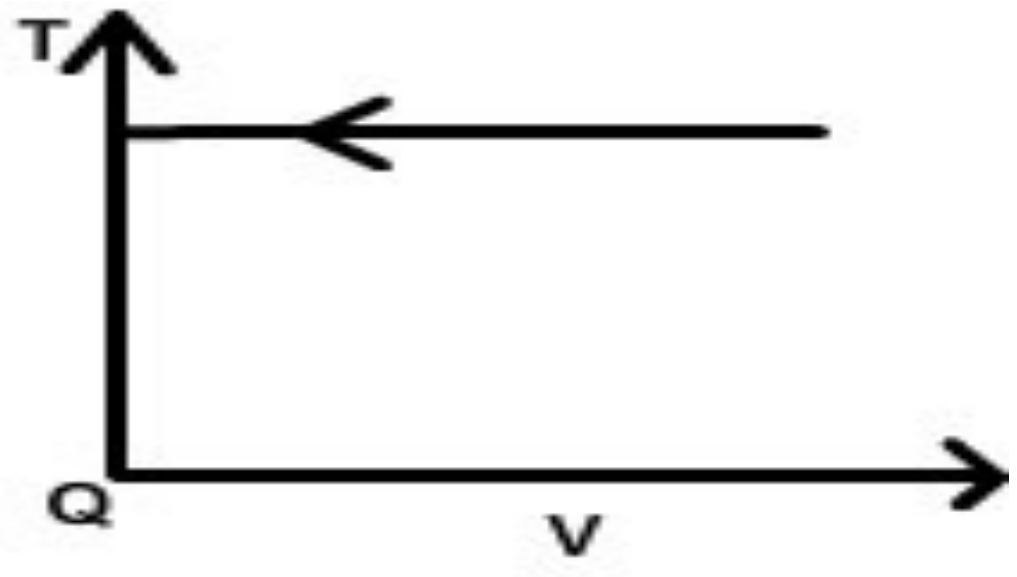
- **Isochoric (or isometric) process**: A process during which the specific volume *v* remains constant





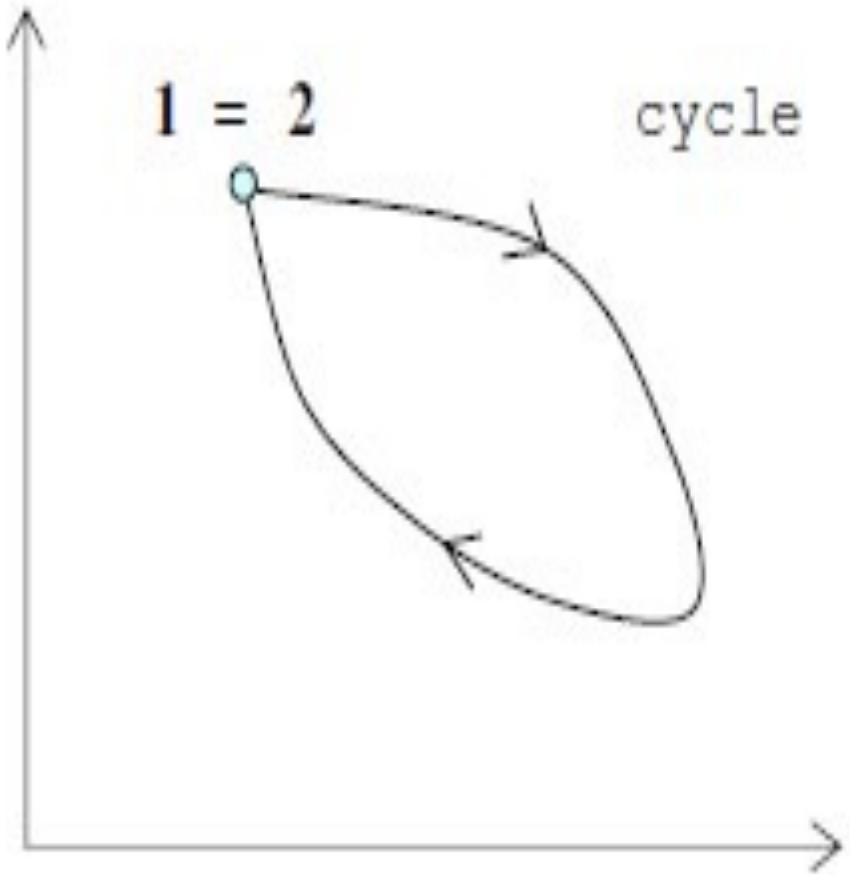
TYPES OF PROCESSES

Isothermal process: A process during which the temperature T remains constant.



TYPES OF THERMODYNAMIC PROCESSES

- **Cyclic process** - when a system in a given initial state goes through various processes and finally return to its initial state, the system has undergone a cyclic process or cycle.
- **Reversible process** - it is defined as a process that, once having take place it can be reversed. In doing so, it leaves no change in the system or boundary.
- **Irreversible process** - a process that cannot return both the system and surrounding to their original conditions



TYPES OF THERMODYNAMIC PROCESSES

- **Adiabatic process** - a process that has no heat transfer into or out of the system. It can be considered to be perfectly insulated.
- **Isentropic process** - a process where the entropy of the fluid remains constant.
- **Polytropic process** - when a gas undergoes a reversible process in which there is heat transfer, it is represented with a straight line, PV^n = constant.
- **Throttling process** - a process in which there is no change in enthalpy, no work is done and the process is adiabatic.

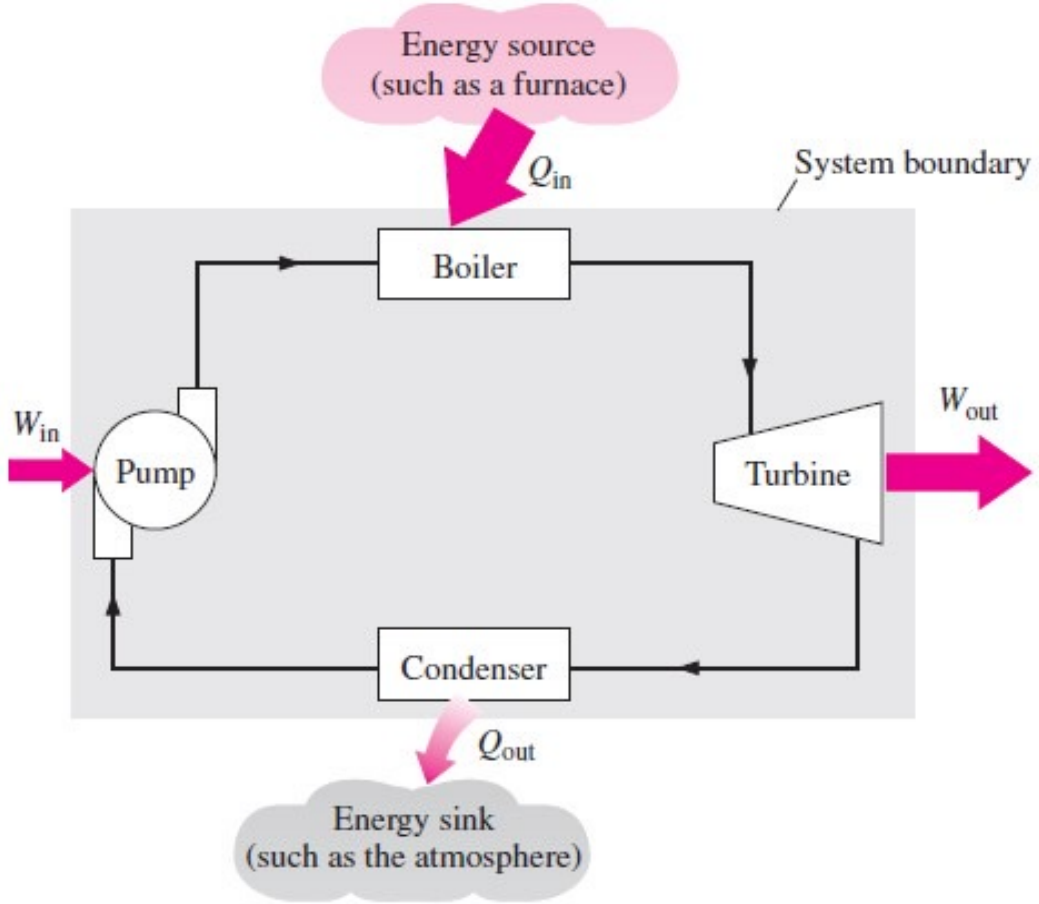
THERMODYNAMIC EQUILIBRIUM

- **No spontaneous change in macroscopic property**
- **Conditions for thermodynamic equilibrium**
- Mechanical equilibrium (equality of forces) (No pressure gradient within the system and also between system & surroundings i.e.$\delta P=0$, or no unbalance force)
- Chemical equilibrium(Chemical composition should not change with time) (No transfer of mass by any chemical process across the boundary of system i.e. diffusion and no unbalanced chemical reaction within the system)
- Thermal equilibrium (Equality of temperatures)(No transfer of heat across the boundary of system when it is separated from universe by means of Diathermic wall- that allows the heat or $\delta T=0$)
- Phase Equilibrium (mass of each phase should remain constant with time)

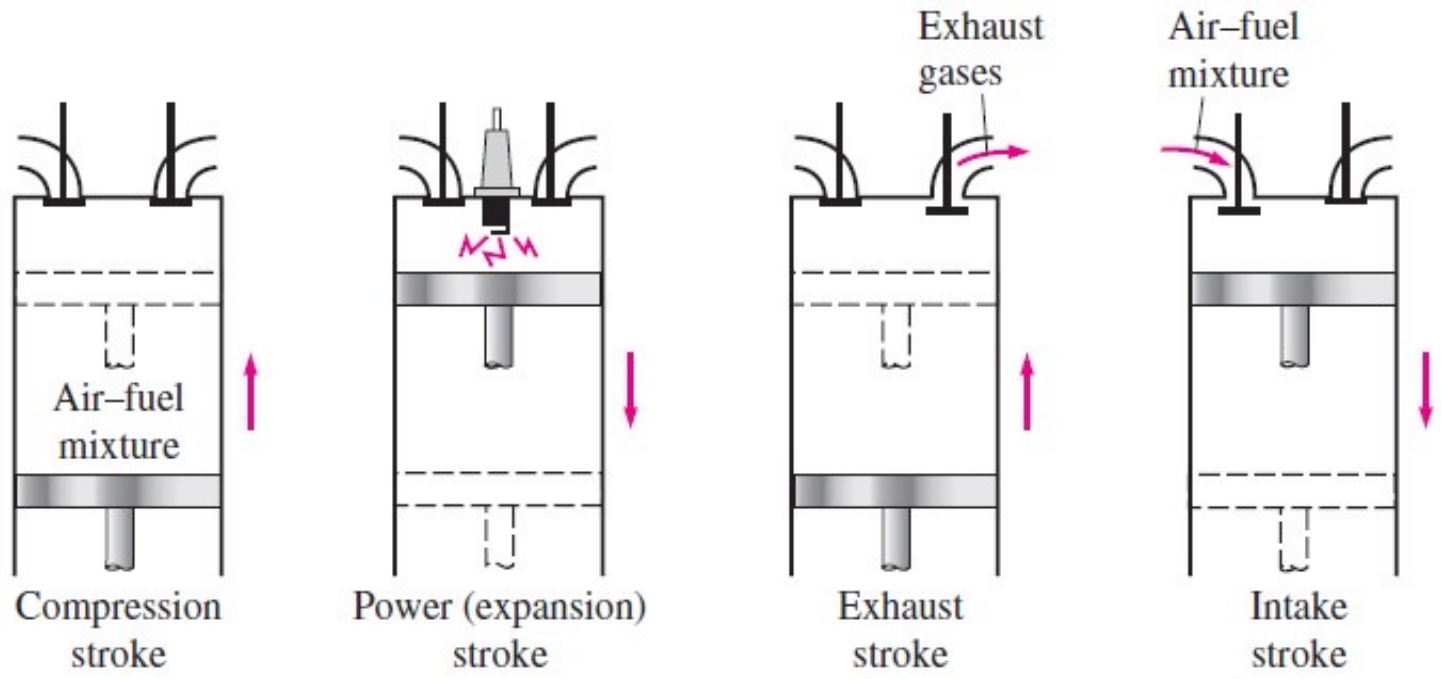
APPLICATION AREAS OF THERMODYNAMICS

- Steam power plant
- I.C.Engine
- Refrigerator and air conditioning
- Gas turbine
- Compressor etc.

STEAM POWER PLANT



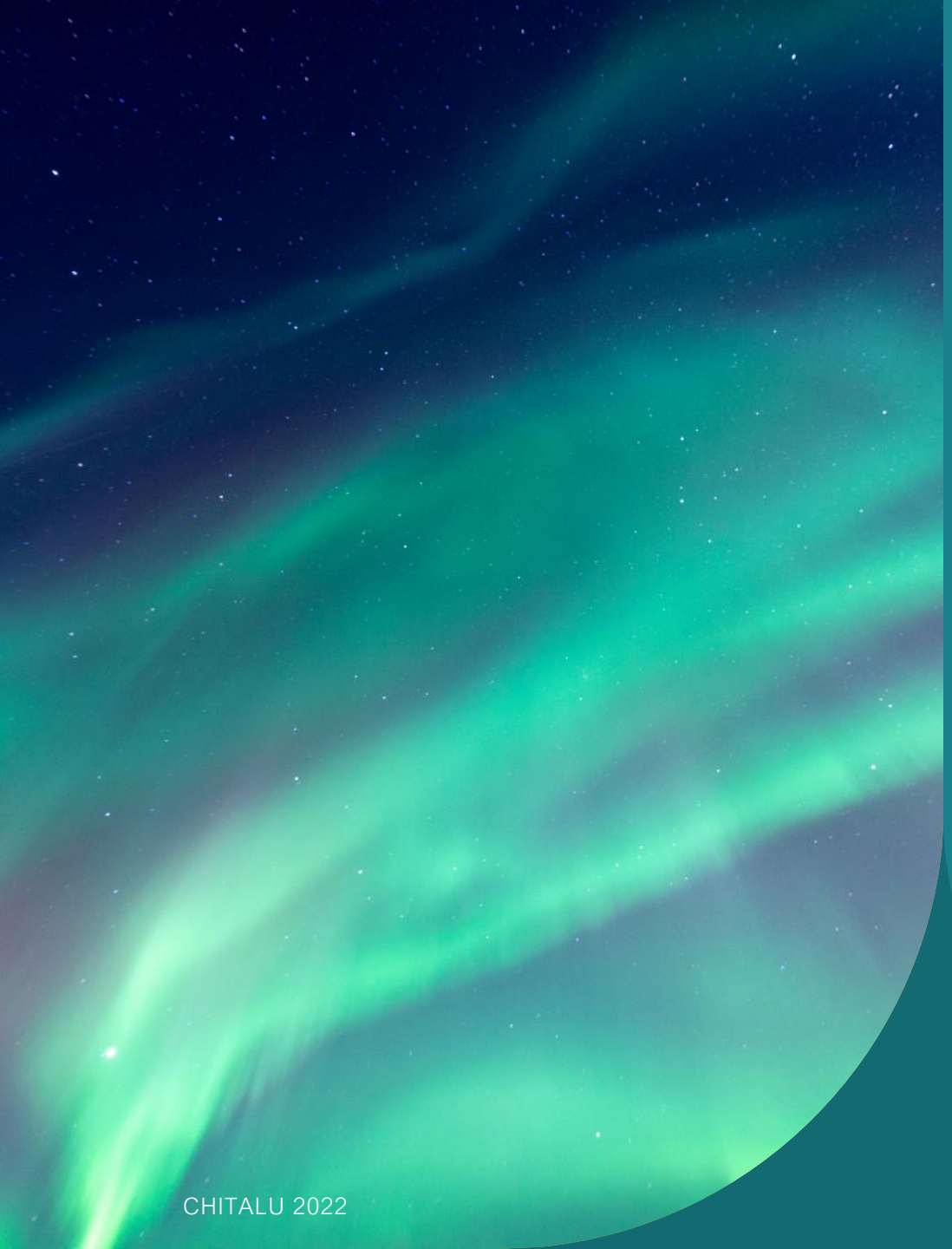
INTERNAL COMBUSTION ENGINE



(*a*) Actual four-stroke spark-ignition engine

“Classical thermodynamics… is the only physical theory of universal content which I am convinced … will never be overthrown.”

Albert Einstein



Thank You

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