Thermodynamics I

Chapter 1

Lecture no.2

Heat, Work, System & State of the Working Fluid

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Heat Q and Work W

Heat transfer ($\boldsymbol{Q}$) and doing work ($\boldsymbol{W}$) are the two everyday means of bringing energy into or taking energy out of a system.

The processes are quite different. Heat transfer, a less organized process, is driven by temperature differences. Work, a quite organized process, involves a macroscopic force exerted through a distance.

Nevertheless, heat and work can produce identical results. For example, both can cause a temperature increase. Heat transfer into a system, such as when the Sun warms the air in a bicycle tire, can increase its temperature, and so can work done on the system, as when the bicyclist pumps air into the tire. Once the temperature increase has occurred, it is impossible to tell whether it was caused by heat transfer or by doing work.

Heat transfer is energy in transit, and it can be used to do work. It can also be converted to any other form of energy.

Both work and heat involve the transfer of energy. In SI units, the fundamental numerical equivalence of the two is recognized by their being given the same units, Joules, where 1 Joule = 1 Newton x 1 metre. N.m .

Work usually (but not necessarily) involves mechanical movement against a resisting force. An equation used repeatedly was (Work done=force x distance)

$$dW = F\,dL \quad (\textbf{Nm or J})$$

Heat is transferred when an energy exchange takes place due to a temperature difference. When two bodies of differing temperatures are placed in contact then heat will "flow" from the hotter to the cooler body. is quantified as

$$dq = T\,ds \quad (\textbf{J})$$

The rate at which energy transfers take place is commonly expressed in one of two ways.

First, on the basis of unit mass of the fluid, i.e. Joules per kilogram. This was the method used to dimension the terms of the Bernoulli equation.

Secondly, an energy transfer may be described with reference to **time,** Joules per second. This latter method produces the definition of Power (J/s = watt), where the unit, J/s is given the name Watt .

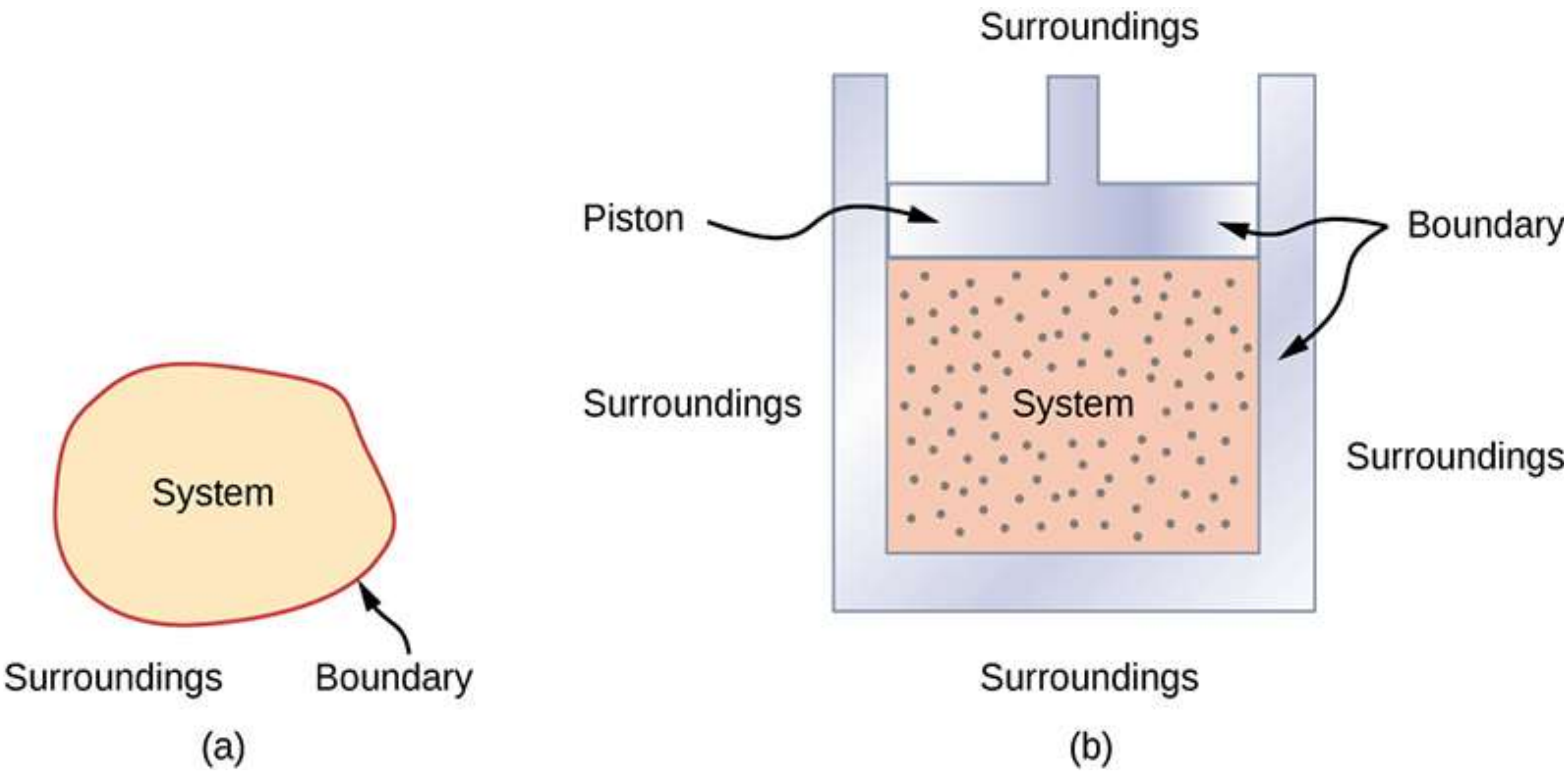
System

A thermodynamic system defined as a collection of matter or a region in space which is under thermodynamic study or analysis a problem.

Let us say for example we are studying the engine of the vehicle, in this case engine is called as the system. Similarly, the other examples of system can be complete refrigerator, air-conditioner, washing machine, heat exchange, a utensil with hot water etc.

A thermodynamic system can undergo internal transformations and exchange energy or matter with the external environment. This concept is very interesting for mechanical engineering and thermal engines.

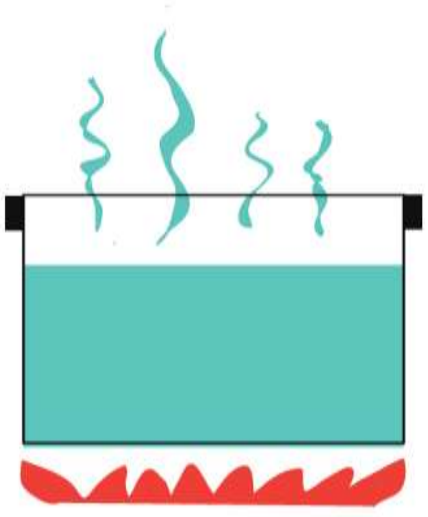
Everything that is part of the exterior of the system is called an environment. The system is covered by the boundary and the area beyond the boundary is called as universe or surroundings. The boundary of the system can be fixed or it can be movable. Between the system and surrounding the exchange of mass or energy or both can occur.



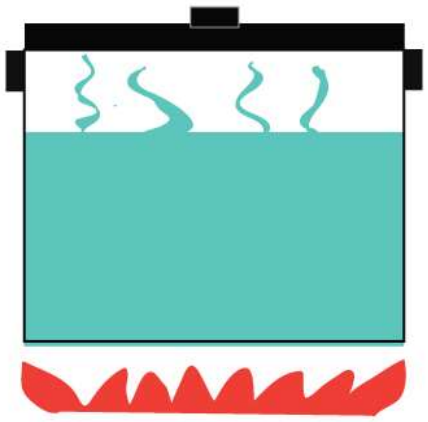
Thermodynamic system

Types of Thermodynamic Systems

There are three mains types of system: open system, closed system and isolated system. All these have been described below:

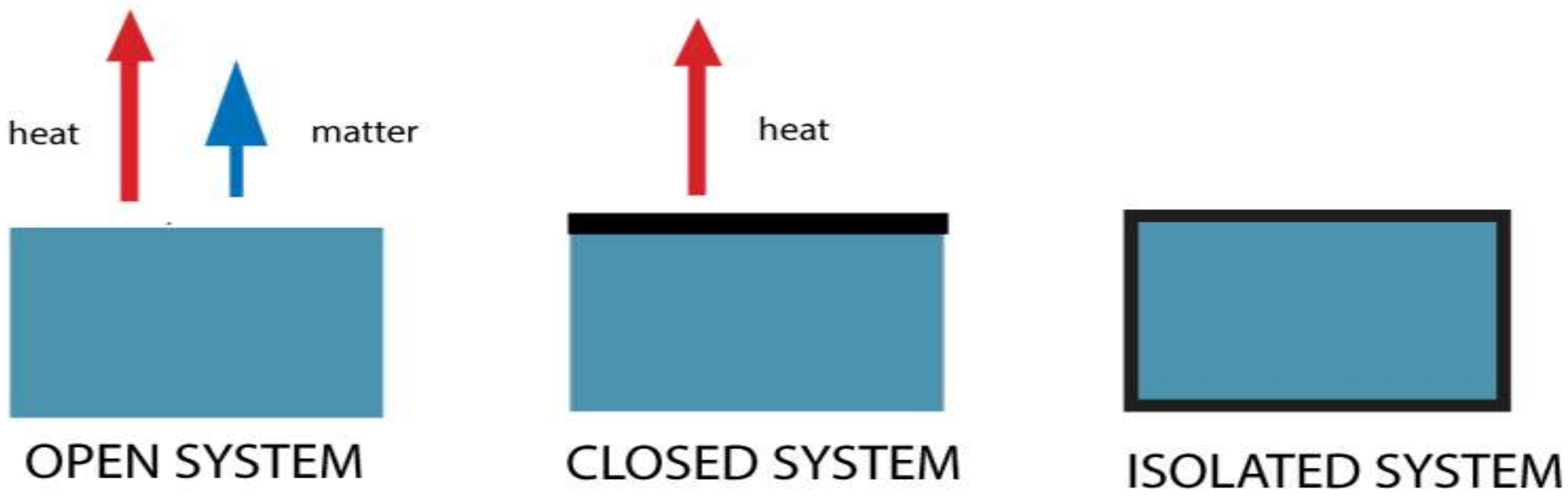


1. **Open system**: The system in which the transfer of mass as well as energy can take place across its boundary is called as an open system. Our previous example of engine is an open system. In this case we provide fuel to engine and it produces power which is given out, thus there is exchange of mass as well as energy. The engine also emits heat which is exchanged with the surroundings. The other example of open system is boiling water in an open vessel, where transfer of heat as well as mass in the form of steam takes place between the vessel and surrounding.



2. **Closed system**: The system in which the transfer of energy takes place across its boundary with the surrounding, but no transfer of mass takes place is called as closed system. The closed system is fixed mass system. The fluid like air or gas being compressed in the piston and cylinder arrangement is an example of the closed system. In this case the mass of the gas remains constant but it can get heated or cooled. Another example is the water being heated in the closed vessel, where water will get heated but its mass will remain same.

3. Isolated system: The system in which neither the transfer of mass nor that of energy takes place across its boundary with the surroundings is called as isolated system. For example if the piston and cylinder arrangement in which the fluid like air or gas is being compressed or expanded is insulated it becomes isolated system. Here there will neither transfer of mass nor that of energy. Similarly hot water, coffee or tea kept in the thermos flask is closed system. However, if we pour this fluid in a cup, it becomes an open system.



State of Working Fluid

A working fluid is a gas or liquid that primarily transfers force, motion, or mechanical energy. Examples without phase change include air or hydrogen in hot air engines such as the Stirling engine, air or gases in gas-cycle heat pumps, etc.

A thermodynamic state is the macroscopic condition of a thermodynamic system as described by its particular thermodynamic parameters. The state of any thermodynamic system can be described by a set of thermodynamic parameters, such as temperature, pressure, density, composition, independently of its surroundings or history.

The parameters required to specify the state depend on the characteristics of the system. There is an optimal ensemble of parameters that uniquely specify the state, and all other parameters can be derived from these. The *state postulate* says that the state of a simple compressible system is completely specified by two independent, intensive properties.

Important Terms and Concepts in Thermodynamics

Density:

This equation is well-known but used often in thermodynamics, therefore we will shortly introduce the *density* to be

$$\rho = \frac{m}{V} \quad \left(\frac{kg}{m^3}\right)$$

This equation allows simplification of the specific volume (volume normalized to mass) to be simply expressed as

$$v = \frac{V}{m} = \frac{1}{\rho} \quad \left(\frac{m^3}{kg}\right)$$

We will use this function when introducing a specific variable, *i.e.*, thermodynamic variables normalized to the mass.

- Control Volume: Thermodynamics uses *control volumes* in order to study changes of the important thermodynamic variables, *e.g.*, the temperature. Often, a process is described conveniently if a suitable control volume is chosen. It requires some expertise and experience to choose control volumes correctly. In general, a *thermodynamic system* is referred to as a control volume for which the thermodynamic state variables (which we will introduce in a moment) are being studied.

- The state of a thermodynamic system : is defined by the current thermodynamic state variables, *i.e.*, their values. Changes of states imply changes in the thermodynamic state variables.

- Thermodynamic process is referred to as the transformation of a thermodynamic system from an initial thermodynamic state (which is described by the thermodynamic state variables) to a second thermodynamic state. The changes induced can be read from the change of the thermodynamic state variables.

The following lists the important thermodynamic state variables :

- **Pressure**, denoted p and measured in Pa
- **Absolute temperature**, denoted T measured in K
- **Volume**, denoted V and measured in m^3, Specific volume (normalized to the mass), denoted v and measured in $m^3\ kg^{-1}$
- **Heat**, denoted Q and measured in J; specific heat (normalized to mass), denoted q and measured in $J\ kg^{-1}$
- **Enthalpy**, denoted H and measured in J; specific enthalpy (normalized to mass), denoted h and measured in $J\ kg^{-1}$
- **Entropy**, denoted S and measured in $J\ K^{-1}$; specific entropy (normalized to mass), denoted s and measured in $J\ K^{-1}\ kg^{-1}$

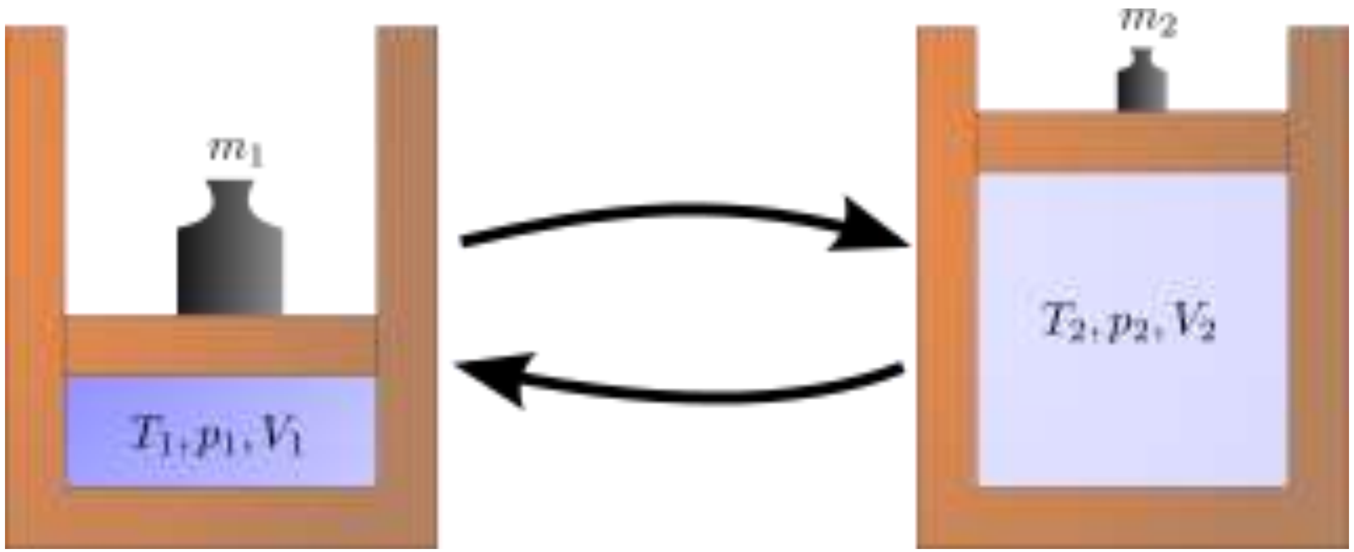
These variables are classified as either being *intensive*, that means they do not scale with the amount of substance contained in the system (temperature being a typical example), or *extensive* that means they scale with the amount of substance contained in the system (volume being a typical example). Some of these variables exist as *specific* variables which means they are normalized to the mass. These variables are usually denoted by lower case letters, *e.g.*, h for specific enthalpy, s for specific entropy, or v for specific volume. Furthermore, variables may sometimes be normalized to a specific time, especially if dynamic processes are to be considered

Reversible work & Irreversible work

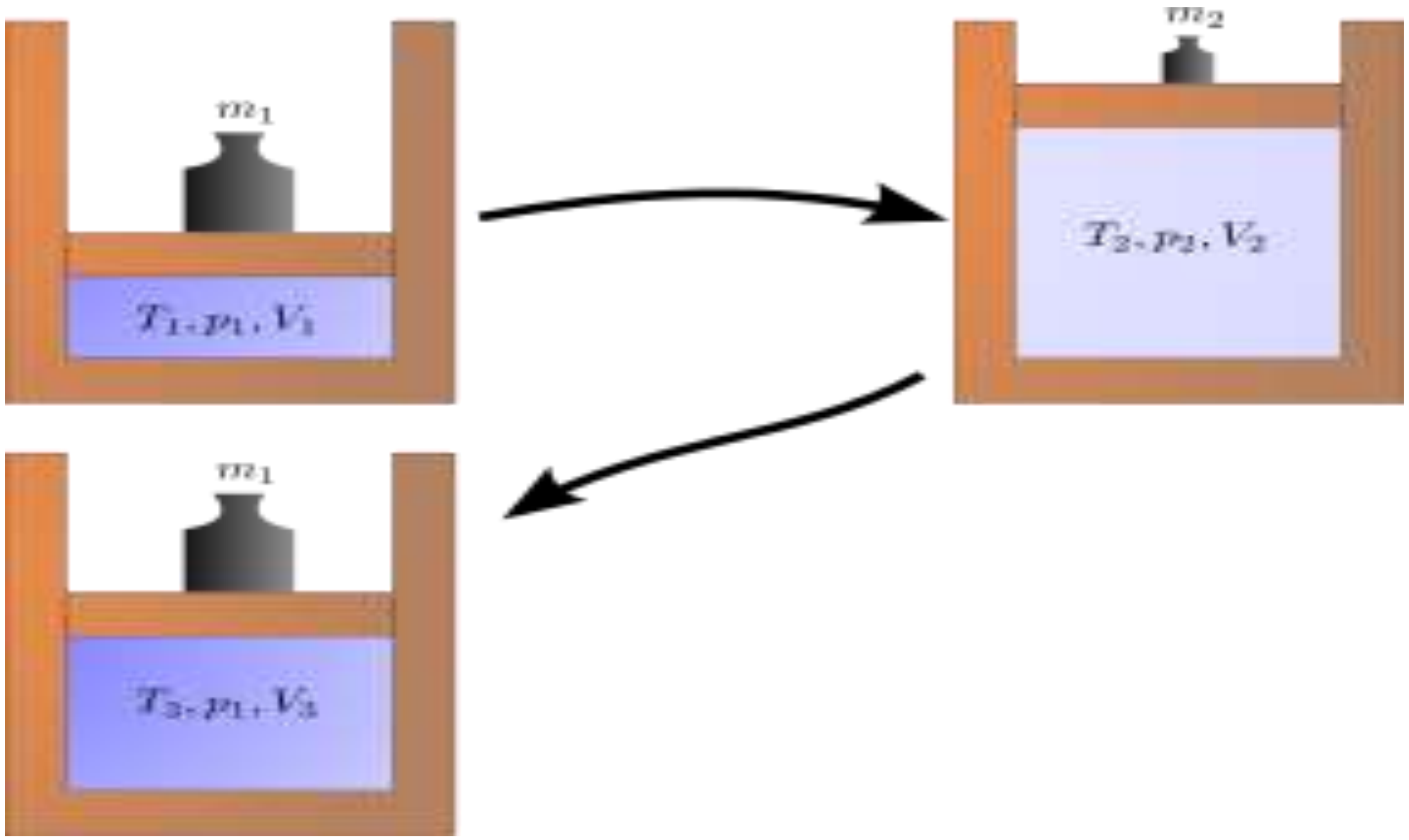
A reversible process is a process whose direction can be reversed to return the system to its original state by inducing infinitesimal changes to some property of the system's surroundings. Throughout the entire reversible process, the system is in thermodynamic equilibrium with its surroundings. Having been reversed, it leaves no change in either the system or the surroundings.

A process can be reversible only when its satisfying two conditions :

- Dissipative force must be absent.
- The process should occur in infinite small time.



Reversible work uses the same process, in reverse, to return to the starting position



Irreversible work uses a different path to return to the starting position, thus changing the surrounding environment

Pressure :

Pressure measurement

It is the analysis of an applied force by a fluid (liquid or gas) on a surface. The pressure is typically measured in units of force per unit of surface area. Many techniques have been developed for the measurement of pressure and vacuum. Instruments used to measure and display pressure in an integral unit are called pressure meters or pressure gauges or vacuum gauges. A manometer is a good example, as it uses the surface area and weight of a column of liquid to both measure and indicates pressure. Likewise, the widely used Bourdon gauge is a mechanical device, which both measures and indicates and is probably the best-known type of gauge.

A vacuum gauge is a pressure gauge used to measure pressures lower than the ambient atmospheric pressure, which is set as the zero points, in negative values (e.g.: −15 psig or −760 mmHg equals total vacuum). Most gauges measure pressure relative to atmospheric pressure as the zero points, so this form of reading is simply referred to as "gauge pressure". However, anything greater than a total vacuum is technically a form of pressure. For very accurate readings, especially at very low pressures, a gauge that uses the total vacuum as the zero points may be used, giving pressure readings on an absolute scale.

Other methods of pressure measurement involve sensors that can transmit the pressure reading to a remote indicator or control system (telemetry). Absolute, gauge, and differential pressures — zero reference. Everyday pressure measurements, such as for vehicle tire pressure, are usually made relative to ambient air pressure. In other cases, measurements are made relative to a vacuum or some other specific reference.

Gauge pressure is the pressure relative to atmospheric pressure.
Absolute pressure (or total pressure) , is thus the sum of gauge pressure and atmospheric pressure:

$$\mathbf{P_{abs} = P_{gauge} + P_{atm}}$$

Where, P_{abs} is absolute pressure, P_{gauge} is gauge pressure, and P_{atm} is atmospheric pressure.

Stagnation pressure

The magnitude of stagnation pressure can be derived from Bernoulli Equation For incompressible flow and no height changes. For any two points 1 and 2:

$$\mathbf{P_1 + \frac{1}{2}\,\rho\, v_1^2 = P_2 + \frac{1}{2}\,\rho\, v_2^2}$$

The two points of interest are

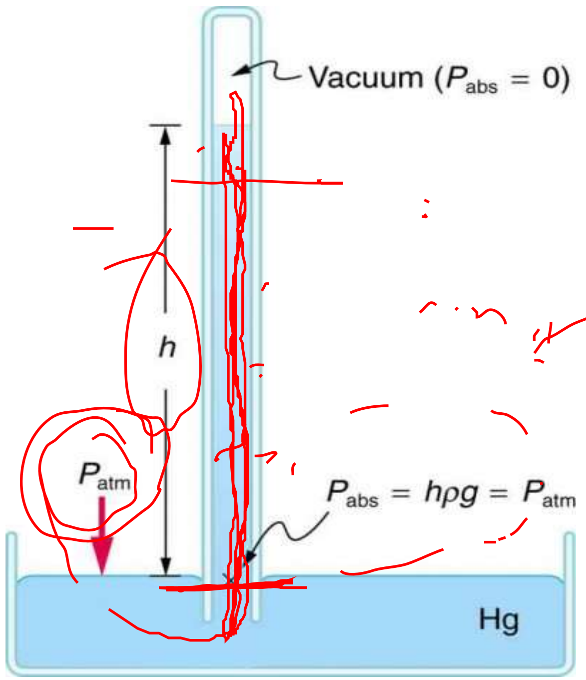
1) In the freestream flow at relative speed v where the pressure is called the "static" pressure, (for example well away from an airplane moving at speed v)

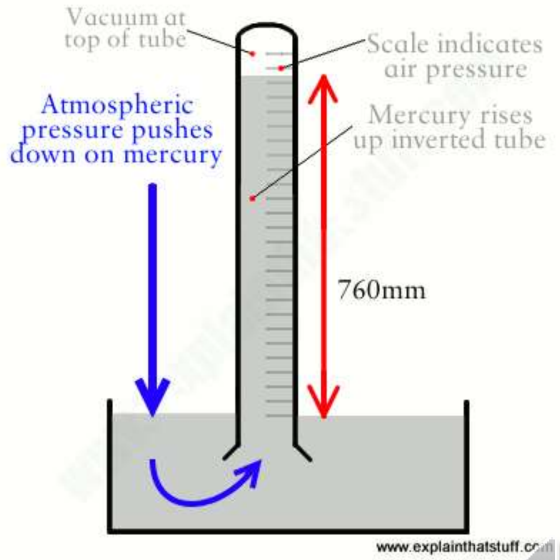
2) At a "stagnation" point where the fluid is at rest with respect to the measuring apparatus (for example at the end of a pitot tube in an airplane). Then

$$\mathbf{P_{Static} + \frac{1}{2}\,\rho\, v^2 = P_{Stagnation} + \frac{1}{2}\,\rho\,(\,0\,)^2}$$

$$\mathbf{P_{Stagnation} = P_{Static} + \frac{1}{2}\,\rho\, v^2}$$

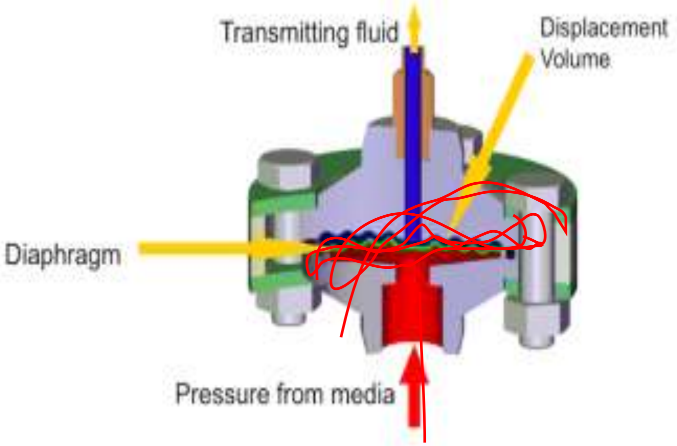
where: P is the stagnation pressure, ρ is the fluid density, v is the speed of fluid, P is the static pressure

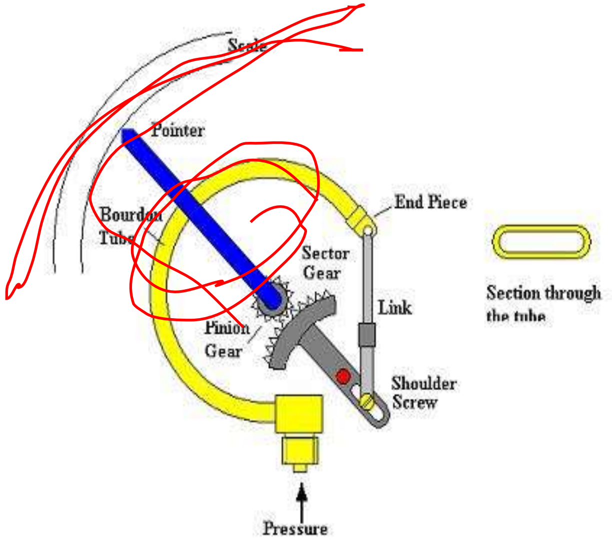




Pressure Application Examples

Type	Definition	Application Examples
Gauge	Reference to atmospheric pressure.	Car Tyre Water Level Measurement Chamber Pressure Hydraulic Applications
Sealed	Referenced to a sealed chamber closed with atmospheric pressure (approximately 1bar).	For use in Aggressive Media Industrial Applications Washdown Environments Food and Beverage
Absolute	The reference is a vacuum (0bar or no pressure).	Barometric Weather Stations and Meteorological Applications
Differential	Measuring the difference between two pressure port readings.	Filter and Pump Monitoring Air Conditioner HVAC Heating Ventilation and Air Conditioning Clean Room Monitoring





Differential Pressure Guage

A diaphragm seal is a thin, flexible wall that separates the media being measured from the pressure measuring instrument.