

Introduction to environmental engineering Thermodynamics
(ChE 2082)
lecture 1

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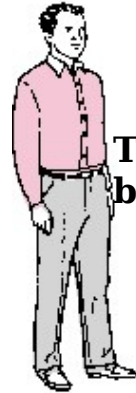
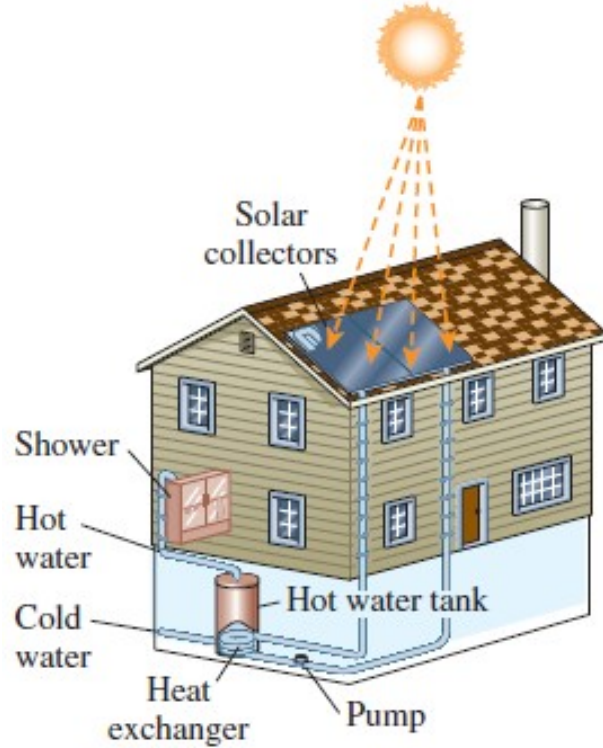
Definition and scope of thermodynamics

Thermodynamics :

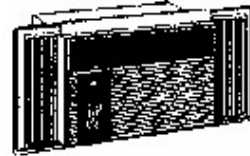
- Science of energy that deals with heat and work and the changes they can produce.
- Branch of physics concerned with heat and temperature and their relation to energy and work
- The word thermodynamics is derived from two Greek words **therme** (heat) and **dynamis** (power).
- The formal study of thermodynamics began in the early nineteenth century after construction and operation of steam engines

- These days the same name is interpreted to include energy transformations on systems like power generation, refrigeration system and relationship among properties of matter.
- Thermodynamics also deals with quantities that are not properties, such as mass flow rates and energy transfers by work and heat.
- **Guggenheim's definition:** “Thermodynamics is ₃ a

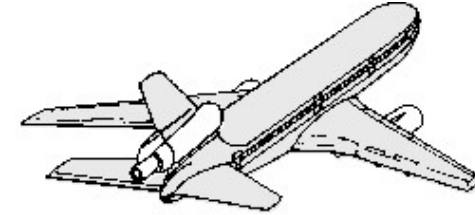
Application Areas of Thermodynamics



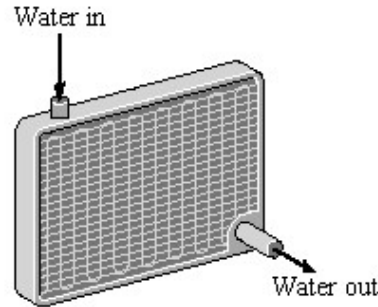
The human body



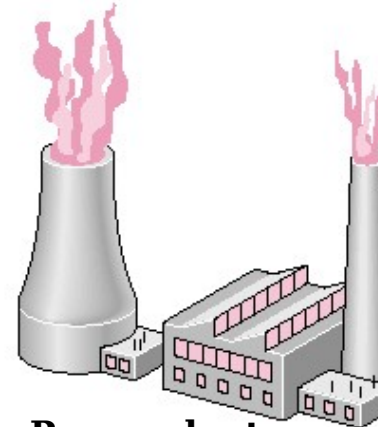
Air-conditioning systems



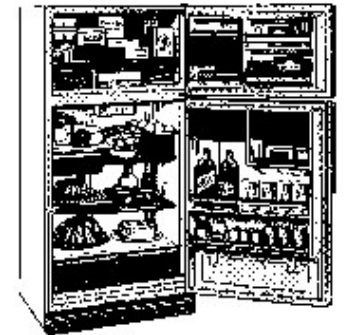
Airplanes



Car radiators



Power plants



Refrigeration systems

All activities in nature involve some interaction between energy and matter; thus, it is hard to imagine an area that does not relate to thermodynamics in some manner.

Engineers & Thermodynamics

- Calculation of heat and work requirements for physical and chemical processes
- Determination of equilibrium conditions
 - ✓ for Chemical reaction
 - ✓ Transfer of chemical species between phases (mass transport)
- Enables him/her to calculate Maximum efficiency of a turbine or refrigerator .
- Knowledge of thermodynamics is required to design any device involving exchange between heat and work or in combustion process.
- Enable them to Design and analysis of automotive engines, rockets, jet engines, and conventional or nuclear

Systems and their behavior

Definition of a system

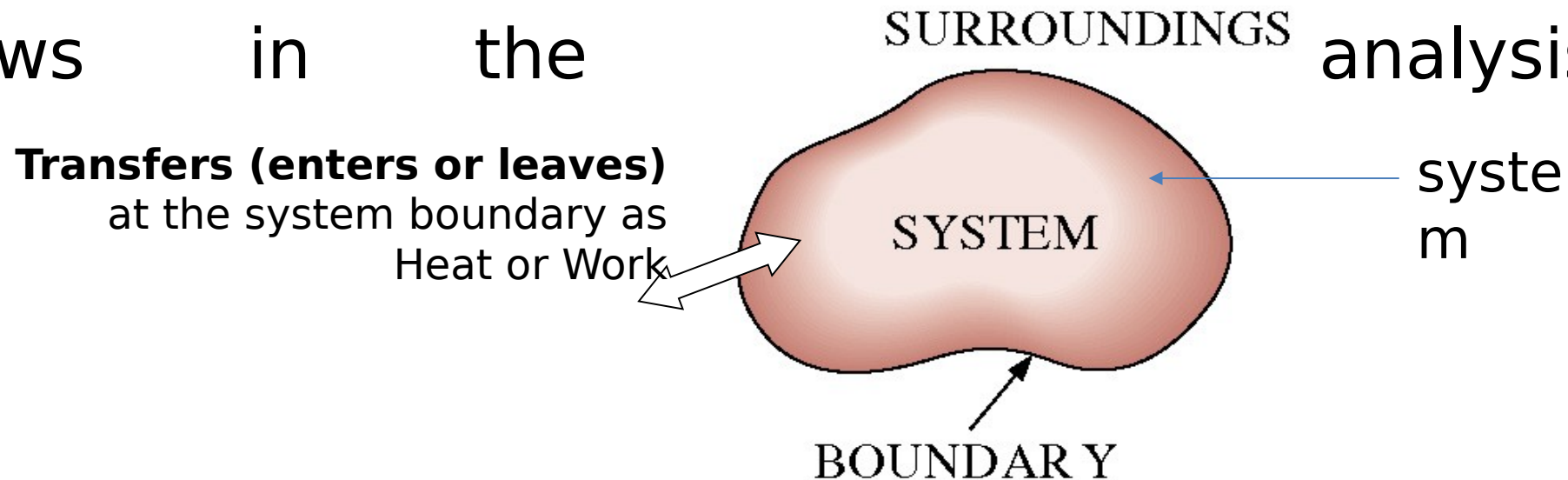
An important step in any engineering analysis is to describe precisely what is being studied.

In thermodynamics 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 matter or a region being under study. It is a limited part of the universe with a boundary that may be a mathematical surface of zero thickness, or a physical barrier between it and the surroundings.
- The composition of the matter inside the system may be fixed or may be changing through chemical or nuclear reactions.
- The shape or volume of the system being analyzed 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 real or imaginary surface that separates the system from its surroundings is called the **boundary**.
- The **boundary of a system** - contact surface shared by both the system and the surroundings. It can be fixed or movable.

- It is essential for the boundary to be represented accurately before proceeding with any thermodynamic analysis.
- The choice of a particular boundary defining a particular system is governed by the convenience it allows in the analysis.



Types of system

Closed system (control mass)

- Material content is fixed- no mass can cross its boundary
- Internal mass changes only due to a chemical reaction
- Exchange energy only in the form of heat or work with the surroundings

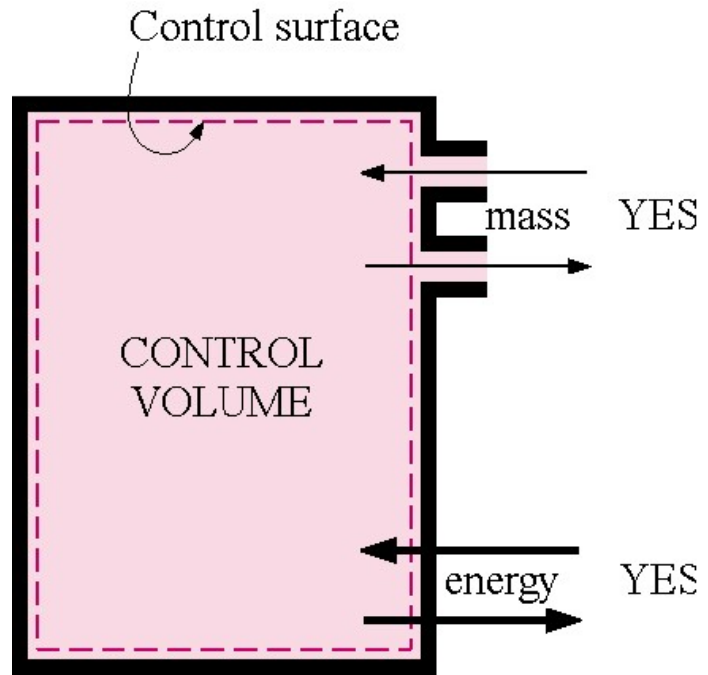
Open system (control volume)

- Systems freely exchange mass and energy with their surroundings

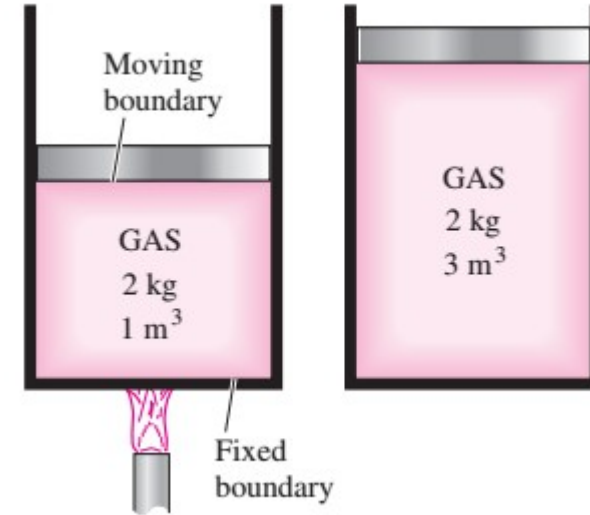
Isolated system:

- Cannot exchange energy and matter
- Does not interact in any way with its surroundings

Examples

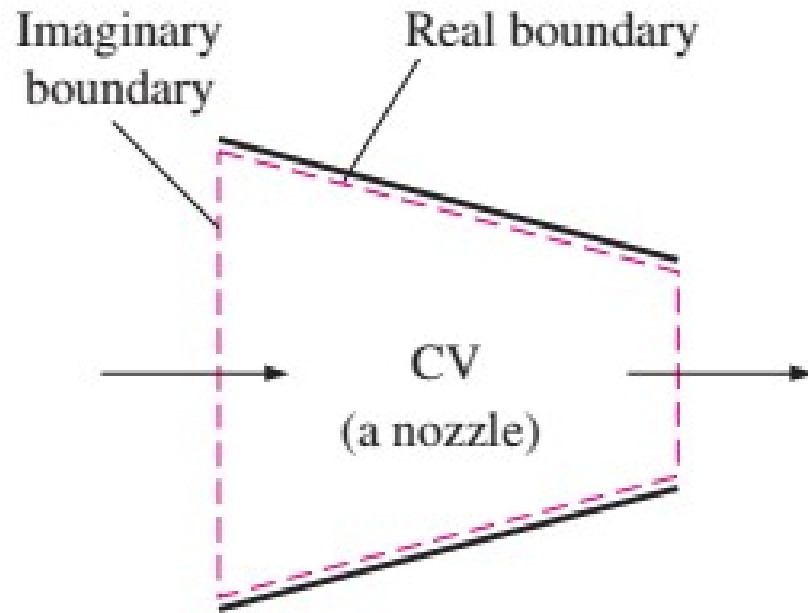


Open system

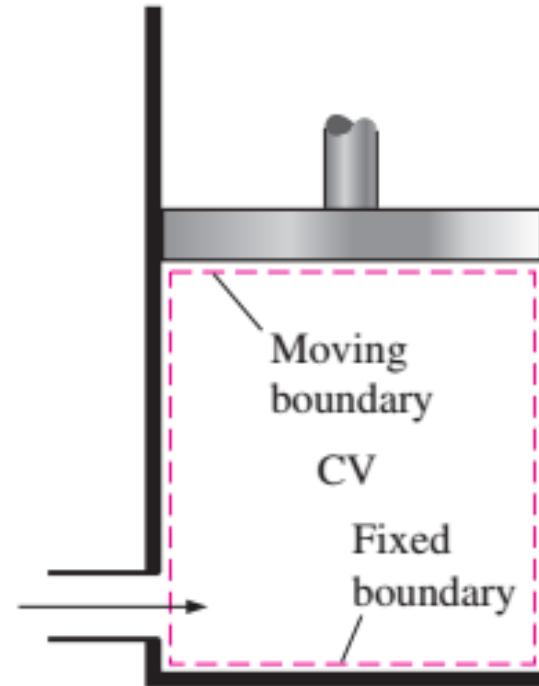


Closed system

A control volume can involve fixed, moving, real, and imaginary boundaries.



A control volume with real and imaginary boundaries



A control volume with fixed and moving boundaries

Microscopic and Macroscopic study Approaches

To study the behavior of substances we have 2 approaches

Microscopic:

- Study behavior of each atom & molecule
- Concerned directly with the structure of matter.
- Find the average behavior based on probability theory (*Statistical thermodynamics*)

Macroscopic:

- Study average behavior of many atom & molecule
- Find the average behavior using instruments (***Classical thermodynamics***)
- System behavior to be evaluated from observations of the overall system

System's property

Thermodynamic Property

- A measurable quantity that defines the condition of a system
- e.g. temperature T , volume V
density ρ , pressure P
mass m

Properties of a system are considered to be either intensive or extensive.

Extensive Vs intensive properties

Intensive properties:

- These properties are not additive and do not depend upon the mass of the system. P, T, refractive index, density, thermal conductivity, etc.

Extensive properties:

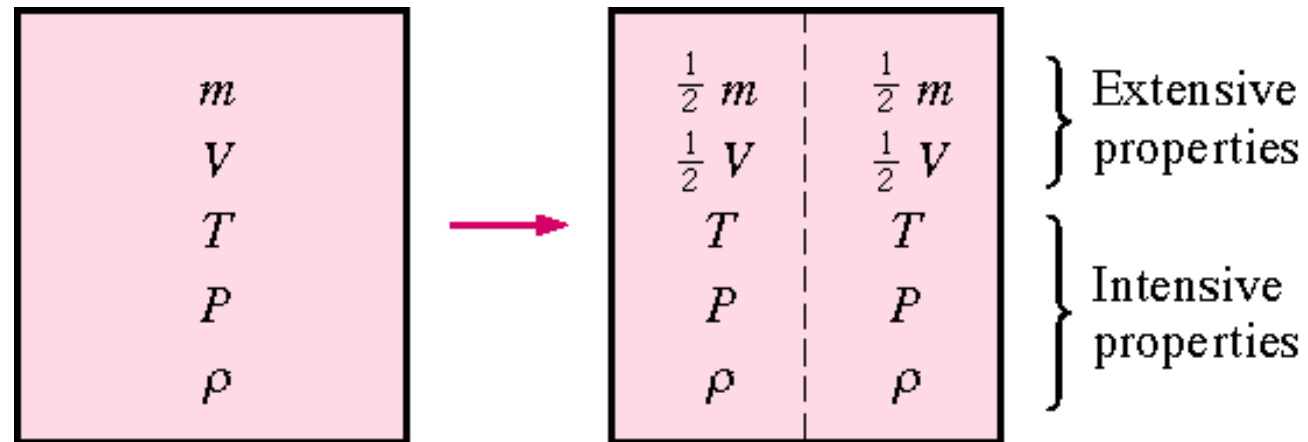
- Total mass, total volume, total momentum, total energy and any mass dependent properties are some examples of extensive properties.
- Additive

Extensive properties per unit mass are called **Specific properties**

Molar volume:

Consider a quantity of substance
 divide into 2 parts

$\left. \begin{array}{l} \text{each} \\ \text{part} \\ \text{will} \\ \text{have} \end{array} \right\} \begin{array}{l} \text{same intensive property} \\ 1/2 \text{ extensive property} \end{array}$



Measures of amount or size

- Any physical quantity can be characterized by dimensions.
- The magnitudes assigned to dimensions are called units.

Fundamental Dimensions	time	– seconds (<i>s</i>)
	length	– meter (<i>m</i>)
	mass	– kilogram (<i>kg</i>)
	quantity	– mole

Others such as velocity V , energy E , and volume V are expressed in terms of the primary dimensions and are called **secondary dimensions, or derived dimensions**

TABLE 1–1	
The seven fundamental (or primary) dimensions and their units in SI	
Dimension	Unit
Length	meter (m)
Mass	kilogram (kg)
Time	second (s)
Temperature	kelvin (K)
Electric current	ampere (A)
Amount of light	candela (cd)
Amount of matter	mole (mol)

Derived Dimensions $\left\{ \begin{array}{ll} \text{force} & - F = ma & \text{newtons (N)} \\ \text{work} & - W = F\Delta x & \text{joule (J or N.m)} \end{array} \right.$

Prefix

10^3	-	kilo	k	10^{-3}	-	milli	m
10^6	-	mega	M	10^{-6}	-	micro	μ
10^9	-	giga	G	10^{-9}	-	nano	n
10^{12}	-	tera	T	10^{-12}	-	pico	p

Dimensional homogeneity

In engineering, all equations must be dimensionally homogeneous. That is, every term in an equation must have the same unit.

All derived units can be formed by combinations of primary units. Force units, for example, can be expressed as

$$\text{N} = \text{kg} \frac{\text{m}}{\text{s}^2} \quad \text{and} \quad \text{lbf} = 32.174 \text{ lbm} \frac{\text{ft}}{\text{s}^2}$$

They can also be expressed more conveniently as **unity conversion ratios** as

$$\frac{\text{N}}{\text{kg} \cdot \text{m}/\text{s}^2} = 1 \quad \text{and} \quad \frac{\text{lbf}}{32.174 \text{ lbm} \cdot \text{ft}/\text{s}^2} = 1$$

Unity conversion ratios are unitless, and thus such ratios (or their inverses) can be inserted conveniently into any

Example 1

- While solving a problem, a person ended up with the following equation at some stage: where E is the total energy and has the unit of kilojoules.
- $E = 25 \text{ kJ} + 7 \text{ kJ/kg}$

- **Solution** Determine how to correct the error and discuss what may have caused it.

Analysis The two terms on the right-hand side do not have the same units, and therefore they cannot be added to obtain the total energy. Multiplying the last term by mass will eliminate the kilograms in the denominator, and the whole equation will become dimensionally homogeneous

Force

- Newton's second law of motion states that the net force acting on a body is proportional to the product of the mass and the acceleration, written as

$$\mathbf{F=ma}$$

- Its $1 \text{ N} = (1 \text{ kg})(1 \text{ m/s}^2) = 1 \text{ kg} \cdot \text{m/s}^2$
- 1 N is the force required to accelerate a mass of 1 kilogram at the rate of 1 meter per second per second.
- The term weight Newton's second law expressed as:
 $F=mg$

Example 2

At 45° latitude, the gravitational acceleration as a function of elevation z above sea level is given by $g = a - bz$, where $a = 9.807 \text{ m/s}^2$ and $b = 3.32 \times 10^{-6} \text{ s}^{-2}$. Determine the height above sea level where the weight of an object will decrease by 1 percent.

Temperature

- Temperature as a measure of “hotness” or “coldness,
- Based on our physiological sensations, we express the level of temperature qualitatively with words like freezing cold, cold, warm, hot.
- The kelvin scale is related to Celsius scale by

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

The Rankine scale related to Fahrenheit scale by

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

The temperature scale in the two units related as

$$T(R) = 1.8 T(^{\circ}K)$$

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

Temperature and 0th law of thermodynamics

Temperature Scales: To relate temperatures that we read from different devices we need a standard scale of temperature

Ice point (0 °C)

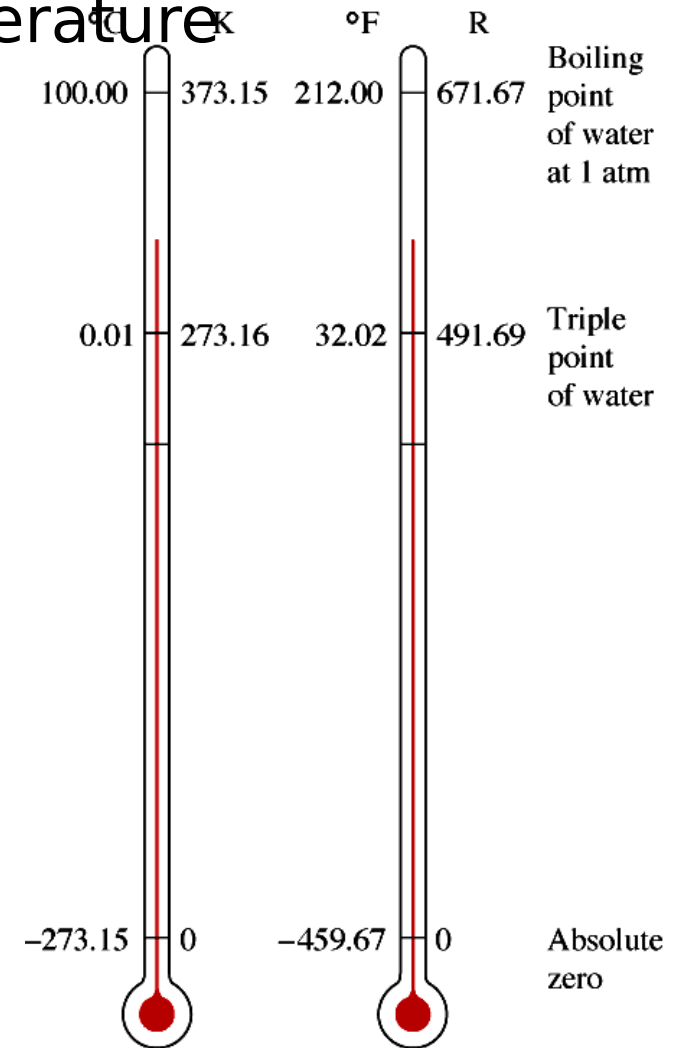
The temperature of a mixture of ice and water in equilibrium at a pressure of 1 atmosphere.

Steam point (100 °C)

The temperature of water and steam which are in equilibrium at a pressure of 1 atmosphere.

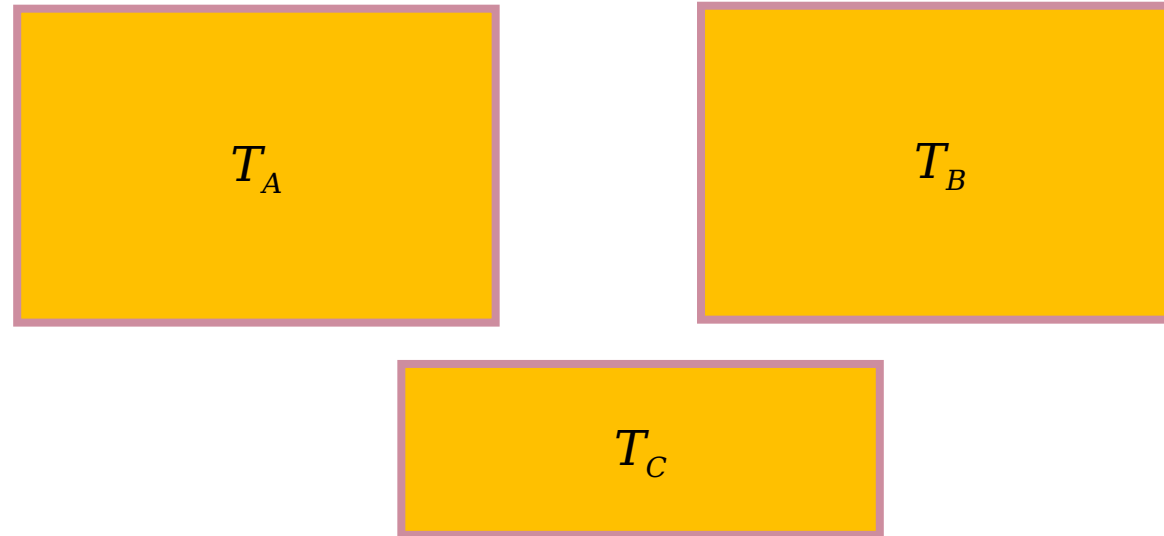
Triple point of water (0.01°C)

A single fixed point at a state in which the solid, liquid and vapor phases of water all exist in equilibrium.



0th law of thermodynamics

When 2 bodies have equality of temperature with a 3rd body, then they have equality of temperature with each other (thermal equilibrium).



$$\text{if } T_A = T_C \quad \& \quad T_B = T_C$$

Example 3

Consider a system whose temperature is 25°C .

a) Express this temperature in K and $^{\circ}\text{F}$.

$$T(^{\circ}\text{F}) = 1.8T(^{\circ}\text{C}) + 32 = (1.8)(25) + 32 = \mathbf{77^{\circ}\text{F}}$$

$$T(\text{R}) = T(^{\circ}\text{F}) + 460 = 77 + 460 = \mathbf{537 \text{ R}}$$

b) If temperature change is given in $^{\circ}\text{C}$ 15 . Express it in K , R and $^{\circ}\text{F}$

$$\Delta T(\text{K}) = \Delta T(^{\circ}\text{C}) = \mathbf{15 \text{ K}}$$

$$\Delta (T)^{\circ}\text{F} = 1.8 \Delta (T) \text{ K} = 45 = \Delta$$

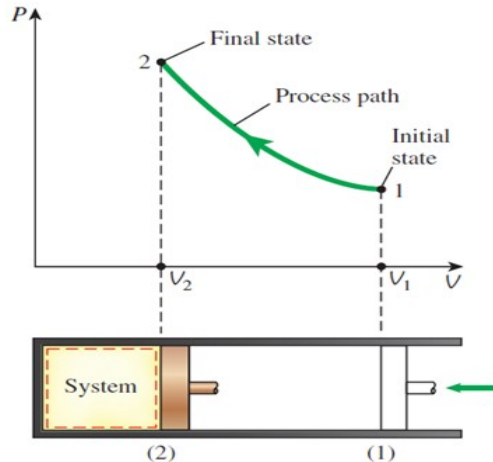
$$(T) \text{ R}$$

Processes and Cycles

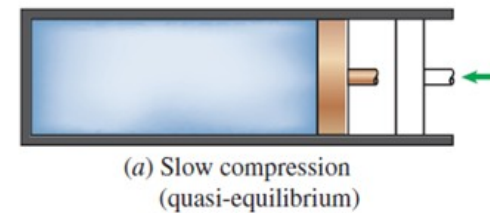
Process: Any change that a system undergoes from one equilibrium state to another.

Path: The series of states through which a system passes during a process. To describe a process completely, one should specify the initial and final states, as well as the path it follows, and the interactions with the surroundings.

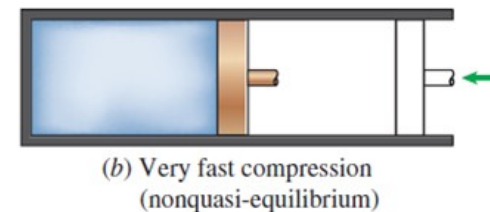
Quasi-equilibrium



quasi-equilibrium process
the system always remains



the process proceeds in a series of states that are always very close to an equilibrium state.



A process between states 1 and 2 and process path

Other process types

- **Adiabatic process:** Any process within an adiabatic system (no heat transfer through the system boundaries)
- **Steady state process:** Variables in the system remain constant with time. System exchanges energy or matter at a constant rate
- **Unsteady state process (transient process):** Variables in the system change with time
- **Cycle:** A process during which the initial and final states are identical

The prefix *iso-* is often used to designate a process for which a particular property remains constant.

- **Isothermal process:** A process during which the temperature T remains constant.
- **Isobaric process:** A process during which the pressure P remains constant.
- **Isochoric (or isometric) process:** A process during which the specific volume v remains constant.

Pressure

- Pressure is defined as a normal force exerted by a fluid (liquid or gas) per unit area.

$$P = \frac{\text{Normal force}}{\text{Area}}$$

- pressure on solid is normal stress

- pressure is defined as force per unit area
its unit is pascal

$$P = h\rho g$$

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

Thus,
 $P = h\rho g$

Units

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

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

$$1 \text{ atm} = 101325 \text{ Pa} = 101.325 \text{ kPa}$$

Gage pressure: The difference between the absolute pressure and the local atmospheric pressure.

Most pressure-measuring devices are calibrated to read zero in the atmosphere, and so they indicate gage pressure.

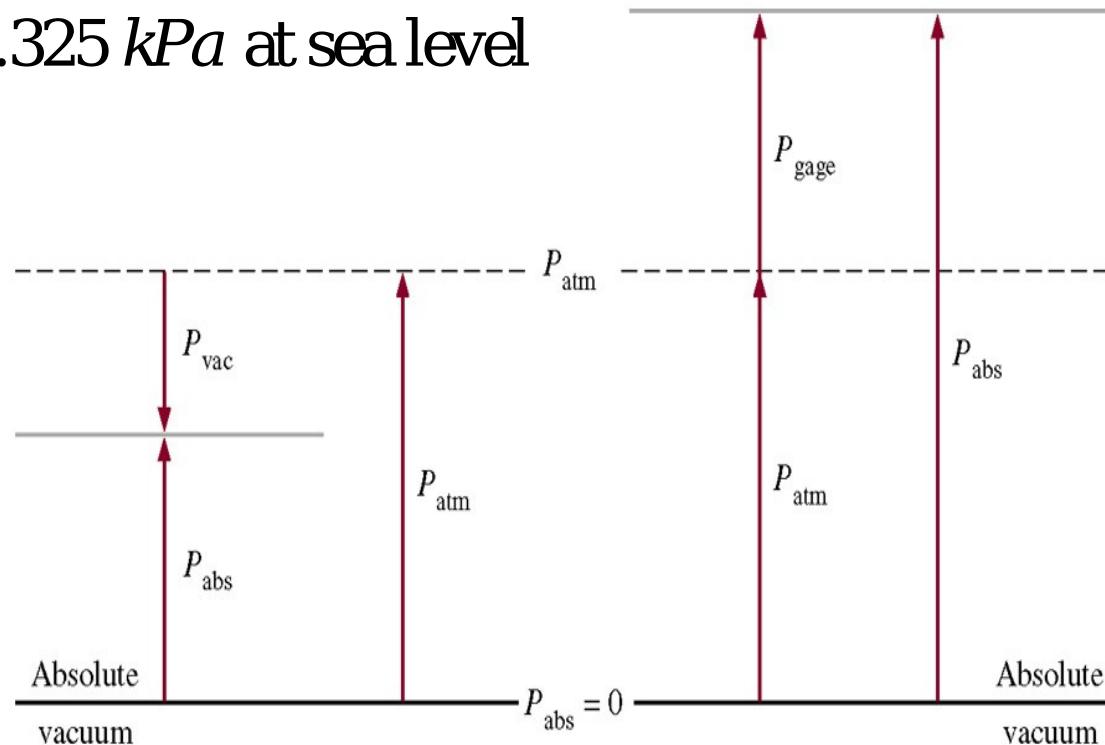
Absolute pressure: The actual pressure at a given position. It is measured relative to absolute vacuum (i.e., absolute zero pressure).

Vacuum pressures: Pressures below atmospheric pressure.

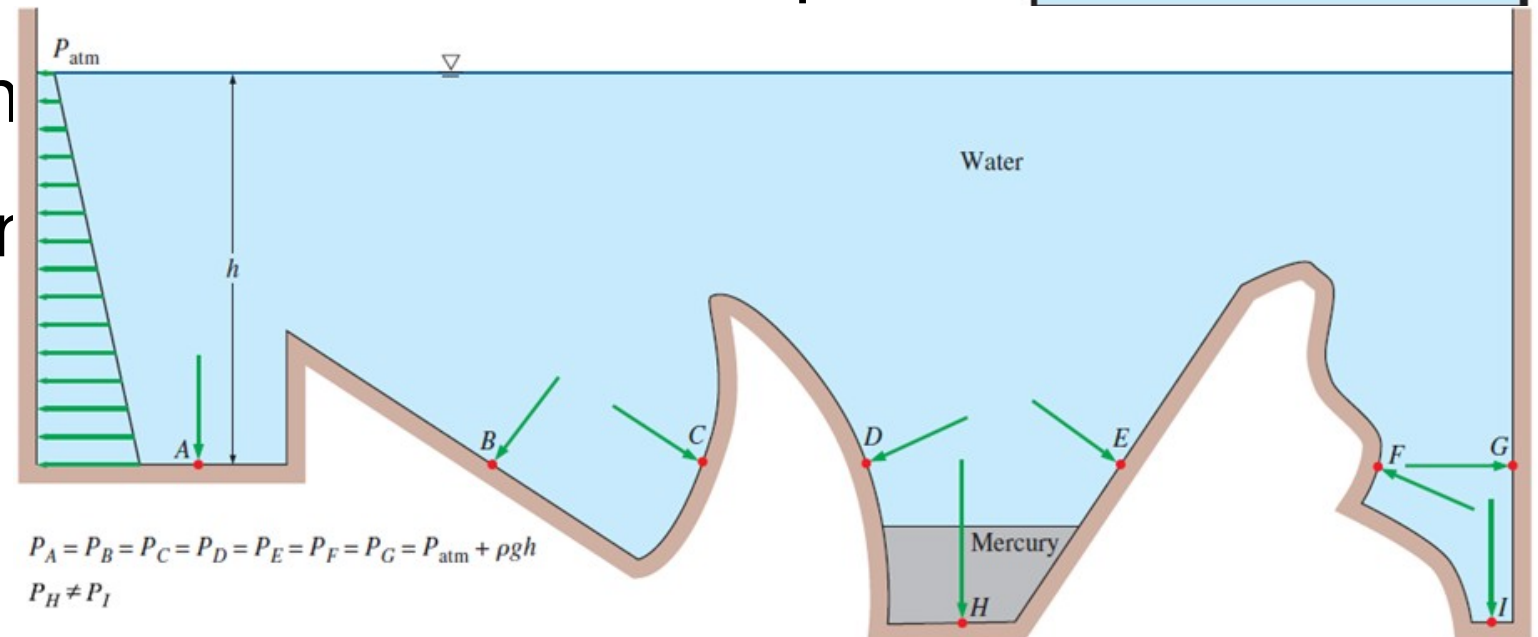
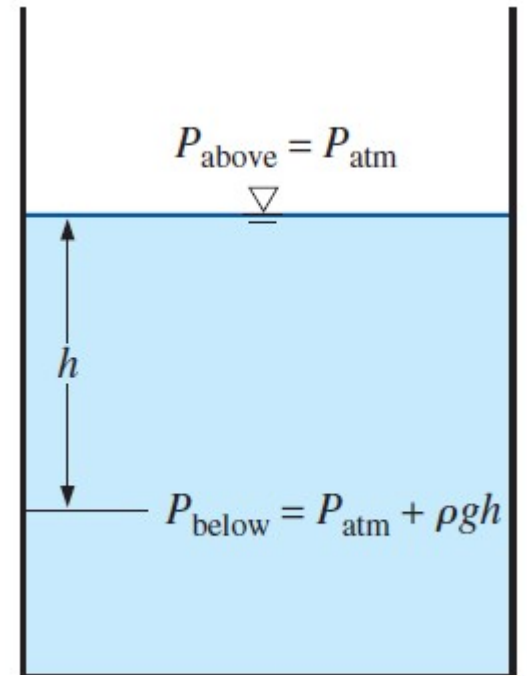
Manometer: used to measure gauge pressure

- In thermodynamics we use **absolute pressure** (P)
- Many devices or instruments measure **gauge pressure** (P_g) which is the pressure above or below the **atmospheric**

pressure (P_{atm} or P_0)
 $P = P_{atm} + P_g$ where $P_{atm} = P_0 = 101.325 \text{ kPa}$ at sea level

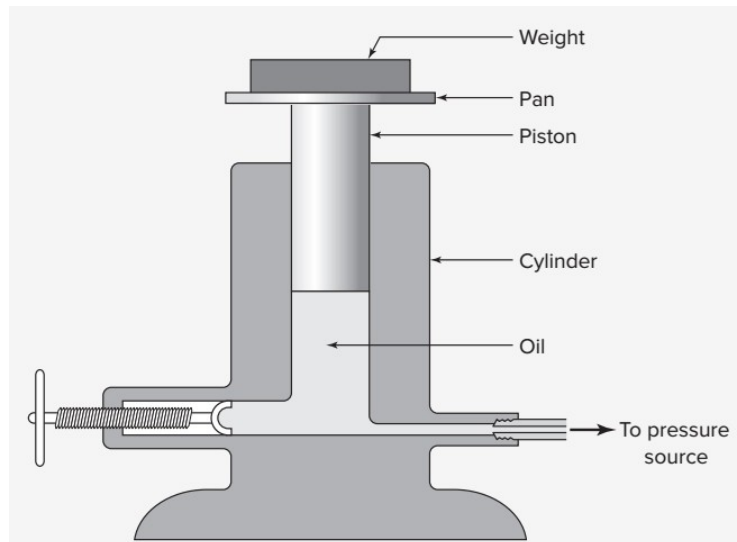


- Pressure in a liquid at rest increase linearly with distance from the free surface (see fig on right)
- Under hydraulic conditions , the pressure is the same at all points on a horizontal plane regardless of geom points are interconn (see on bottom fig)



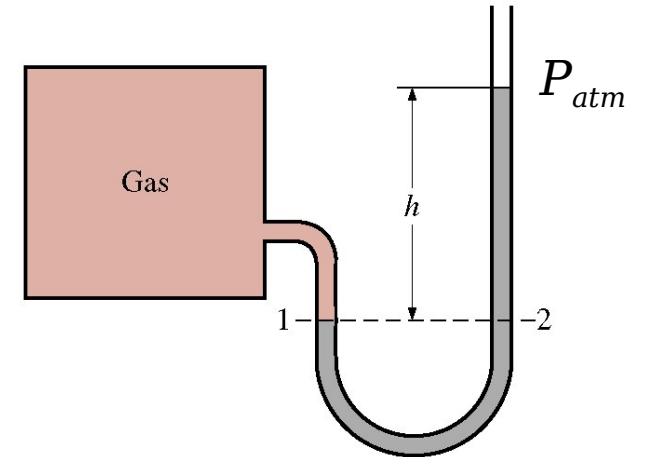
Pressure Measurement Devices

- The primary standard for pressure measurement is the dead-weight gauge in which a known force is balanced by fluid pressure acting on a piston of known area: $P \equiv F/A$



Manometer: used to measure gauge pressure

Points 1 and 2 at the same height and connected by the same liquid have the same pressure.

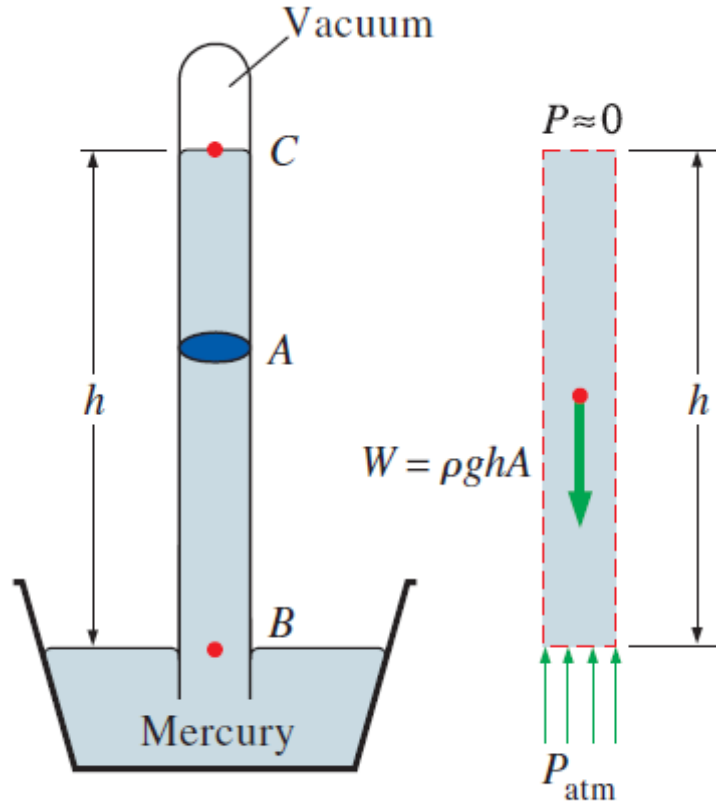


The basic manometer

$$P_1 = P_2 \quad \text{or}$$

$$\frac{F_1}{A_1} = \frac{F_2}{A_2}$$

The Barometer

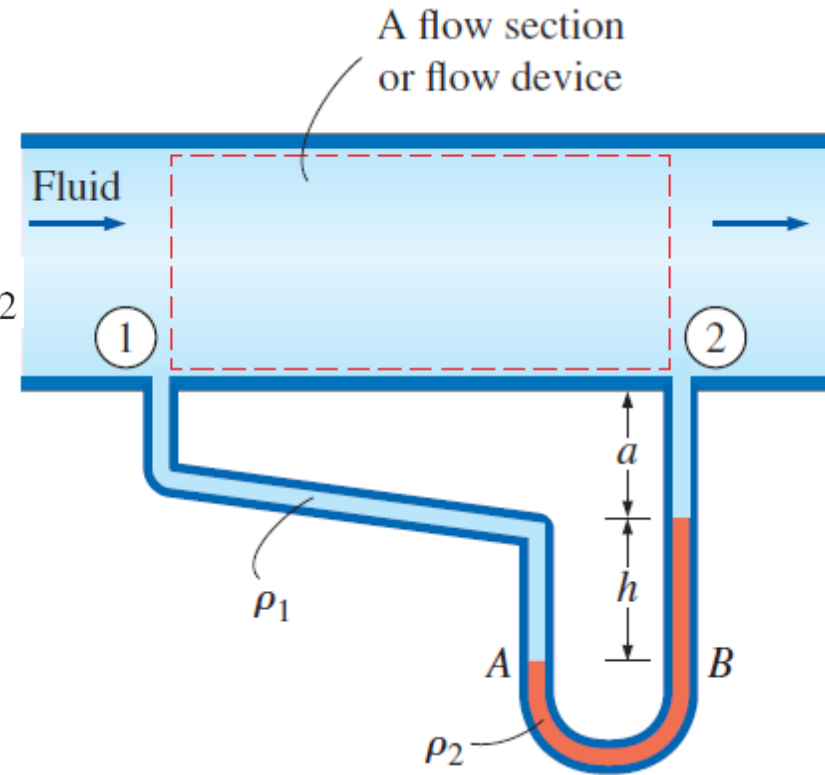


$$P_{\text{atm}} = \rho gh$$

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

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

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



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

Example 4

A dead-weight gauge with a piston diameter of 1 cm is used for the accurate measurement of pressure. If a mass of 5 kg (including piston and pan) brings it into balance, and if $g = 9.8 \text{ m}\cdot\text{s}^{-2}$, what is the gauge pressure being measured? For a barometric pressure of 1.00 bar, what is the absolute pressure?

The force exerted by gravity on the piston, pan, and “weights” is:

$$F = mg = 5 \text{ kg} \times 9.8 \text{ m}\cdot\text{s}^{-2} = 49 \text{ N}$$

$$\begin{aligned} \text{Gauge pressure} \\ &= = 623.887 \text{ KPa} \end{aligned}$$

The absolute pressure is therefore:

$$\begin{aligned} P &= 6.23887 \times 10^5 + 1.00 \times 10^5 = 7.24 \times \\ &10^5 \text{ N}\cdot\text{m}^{-2} \\ &= 724 \text{ kPa} \end{aligned}$$

Example 5

At 27°C the reading on a manometer filled with mercury is 60.5 cm. The local acceleration of gravity is 9.784 m·s⁻². To what pressure does this height of mercury correspond? Given that at 27°C the density of mercury is 13.53 g·cm⁻³

$$P = \rho gh$$

Then,

$$P = 13530 \text{ kg}\cdot\text{m}^{-3} \times 9.784 \text{ m}\cdot\text{s}^{-2} \times 0.605 \text{ m}$$

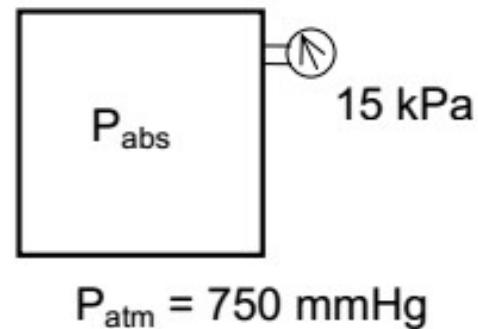
$$= 0.8009 \times 10^5 \text{ N}\cdot\text{m}^{-2}$$

$$= 0.8009 \text{ bar} = 80.09 \text{ kPa}$$

Example 6

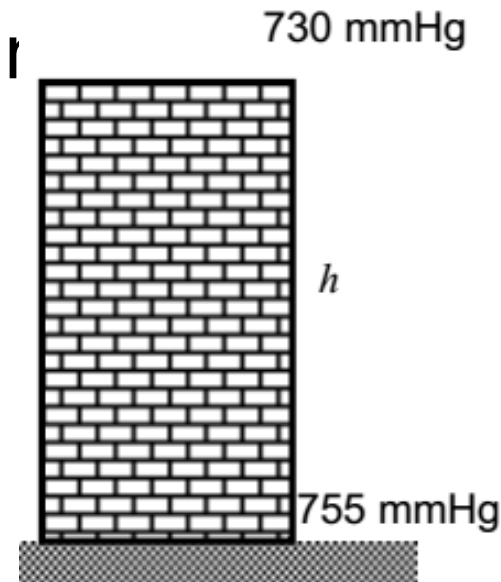
A vacuum gage connected to a tank reads 15 kPa at a location where the barometric reading is 750 mm Hg. Determine the absolute pressure in the tank.

Take $\rho_{\text{Hg}} = 13,590 \text{ kg/m}^3$.



Example 7

The basic barometer can be used to measure the height of a building. If the barometric readings at the top and at the bottom of a building are 730- and 755-mm Hg, respectively, determine the height of the building. Take the densities of air and mercury to be 1.18 kg/m^3 and 13600 kg/m^3 , respectively.



Work

- Work is energy used to cause an object that has mass to move some distance.
- More specifically, work is the energy transfer associated with force acting through a distance.

e.g. a rising piston, a rotating shaft, and an electric wire crossing the system boundaries

- By definition, the quantity of work is given by the equation:

$$dW = \mathbf{F} \cdot d\mathbf{l}$$

where F is the component of force acting along the line

- By convention, work is regarded as positive when the displacement is in the same direction as the applied force and negative when they are in opposite directions.
- Work is done when pressure acts on a surface and displaces a volume of fluid.
- The displacement of the piston is equal to the total volume change of the fluid divided by piston area

$$dW = -PA d\frac{V^t}{A} = -P dV^t$$

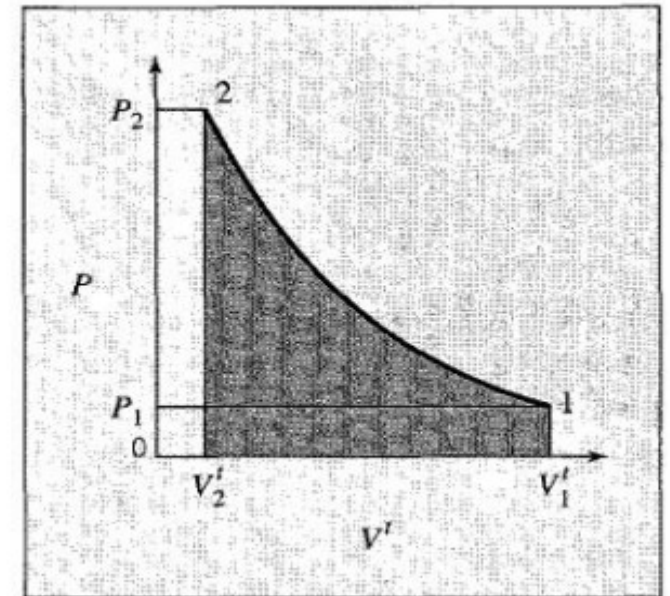
or, since A is constant,

Integrating,

$$dW = -PA d\frac{V^t}{A}$$

$$dW = -P dV^t$$

$$W = - \int_{V_1^t}^{V_2^t} P dV^t$$



Energy

Energy: The ability to cause changes.

Total Energy

(E) *i*

Energy may be contained (stored) in a system as

Microscopic form

Energy related to molecular structure
called **Internal energy**
denoted by **U**

Macroscopic form

Energy related to motion or elevation
of the system e.g.
 $KE = \frac{1}{2} mV^2$ or **$PE = mgz$**

3 ways in which energy is stored as internal energy (U)

Intermolecular potential energy

- Because of forces between molecules.
- At low densities particles are far away intermolecular PE is low then we call it GAS
- If it is assumed to be zero, so we have independent molecules, we call it IDEAL GAS

Molecular kinetic energy

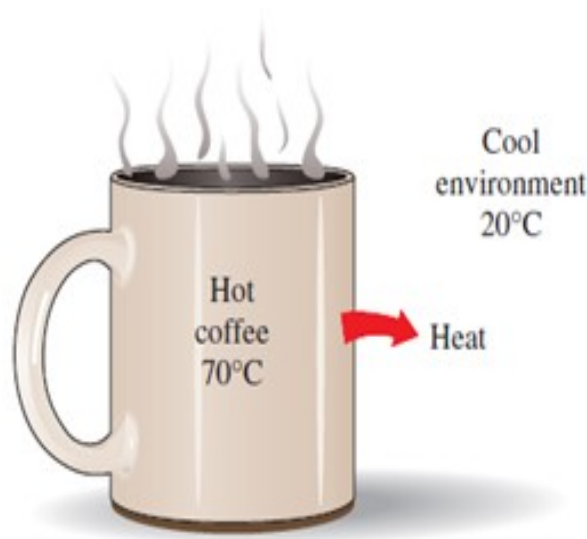
- Because of translational motion of molecules
- It depends on the mass and velocities of the molecules

Intra molecular energy (within individual molecules)

- Because of the molecular and atomic structure and related forces

Conservation of energy principle: During an interaction, energy can change from one form to another, but the total amount of energy remains constant. Thus energy cannot be created or destroyed.

The first law of t
the conservation o



s: An expression of
e.

Heat

- We know from experience that a hot object brought in contact with a cold object becomes cooler, whereas the cold object becomes warmer.
- A reasonable view is that something is transferred from the hot object to the cold one, and we call that something

heat Q

- heat always flows from a higher temperature to a lower one (temperature is driving force)
- Rate of heat transfer proportional to temperature

State and Equilibrium

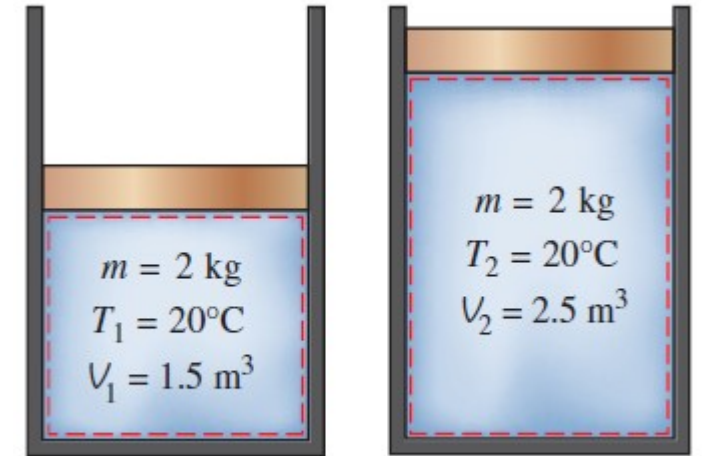
- Thermodynamics deals with *equilibrium* states which is **the** state of balance.
- In an equilibrium state there are no unbalanced potentials (or driving forces) within the system.

Thermal equilibrium: If the temperature is the same throughout the entire system.

Mechanical equilibrium: If there is no change in pressure at any point of the system with time.

Phase equilibrium: If a system involves two phases and when the mass of each phase reaches an equilibrium level and stays there.

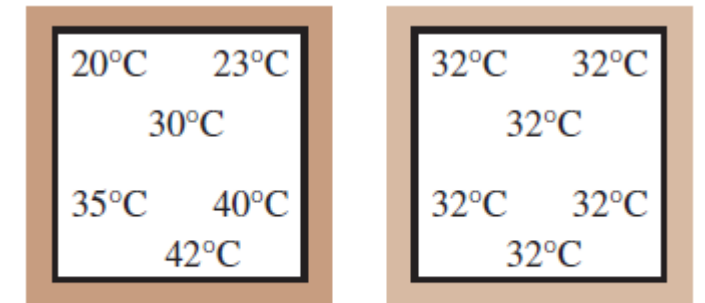
Chemical equilibrium: If the chemical composition of a system does not change with time, that is, no chemical reactions occur.



(a) State 1

(b) State 2

A system at two d/t states



(a) Before

(b) After

Closed system reaching thermal equilibrium