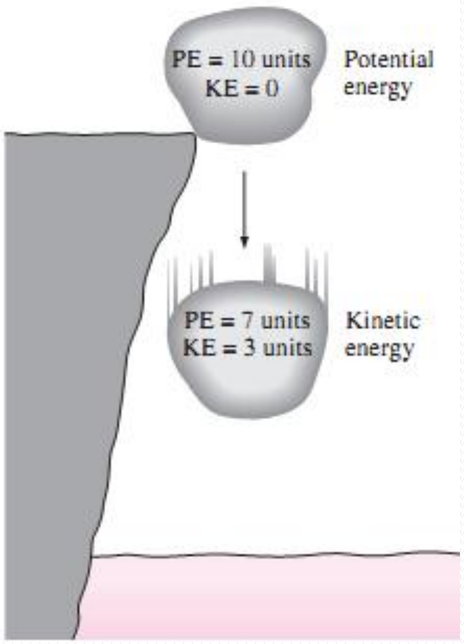
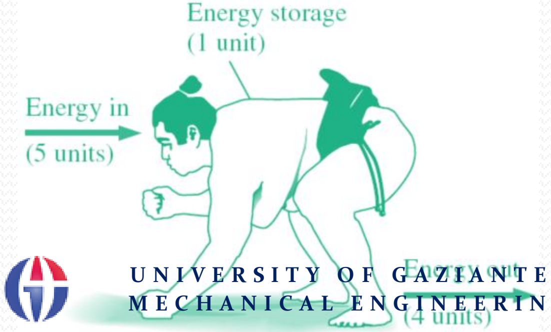
Chapter 2 Some Concepts And Definitions

- **Thermodynamics:** The science of *energy.*
- **Energy:** The ability to cause changes.
- The name *thermodynamics* stems from the Greek words *therme* (heat) and *dynamics* (power).
- **Conservation of energy principle:** During an interaction, energy can change from one form to another but the total amount of energy remains constant.
- Energy cannot be created or destroyed.
- **The first law of thermodynamics:** An expression of the conservation of energy principle.
- The first law asserts that *energy* is a thermodynamic property.

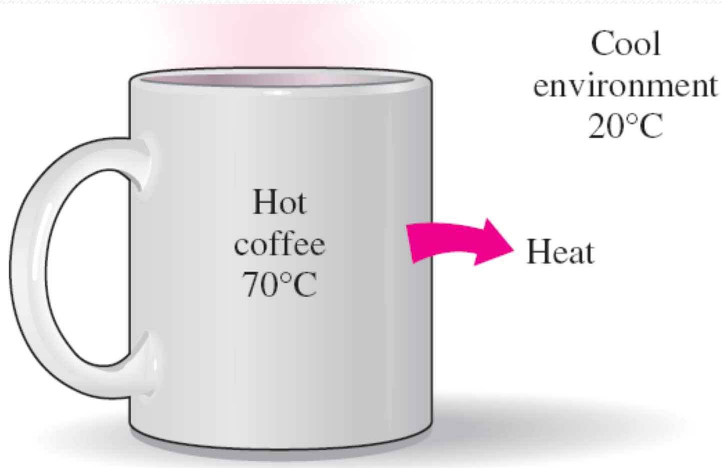




Conservation of energy principle for the human body.

Energy cannot be created or destroyed; it can only change forms (the first law).

- **The second law of thermodynamics: It asserts that energy has *quality* as well as *quantity*, and actual processes occur in the direction of decreasing quality of energy.**
- **Classical thermodynamics: A macroscopic approach to the study of thermodynamics that does not require a knowledge of the behavior of individual particles.**
- **It provides a direct and easy way to the solution of engineering problems and it is used in this text.**
- **Statistical thermodynamics: A microscopic approach, based on the average behavior of large groups of individual particles.**

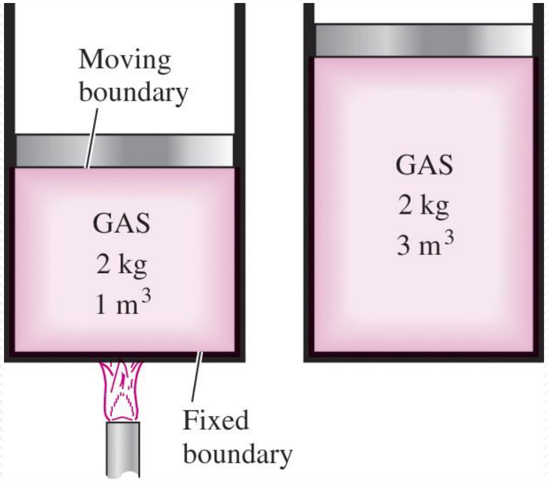


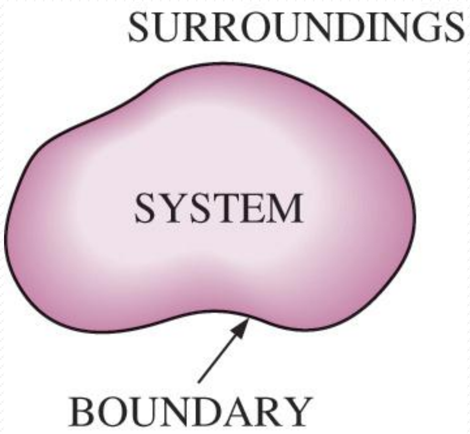
Heat flows in the direction of decreasing temperature.

Control Volumes And Unıts

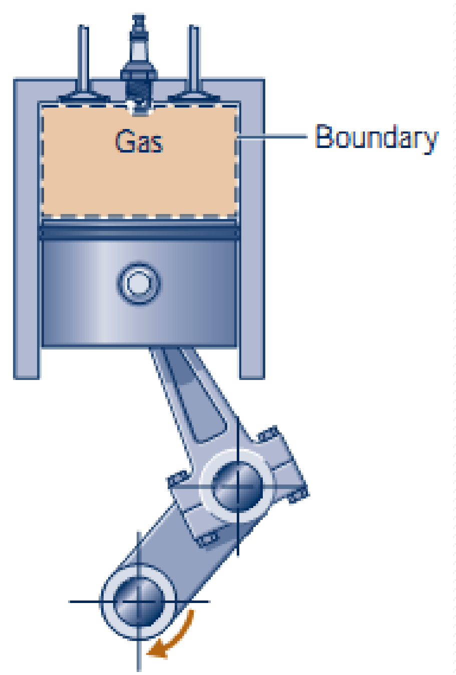
A THERMODYNAMIC SYSTEM AND THE CONTROL VOLUME

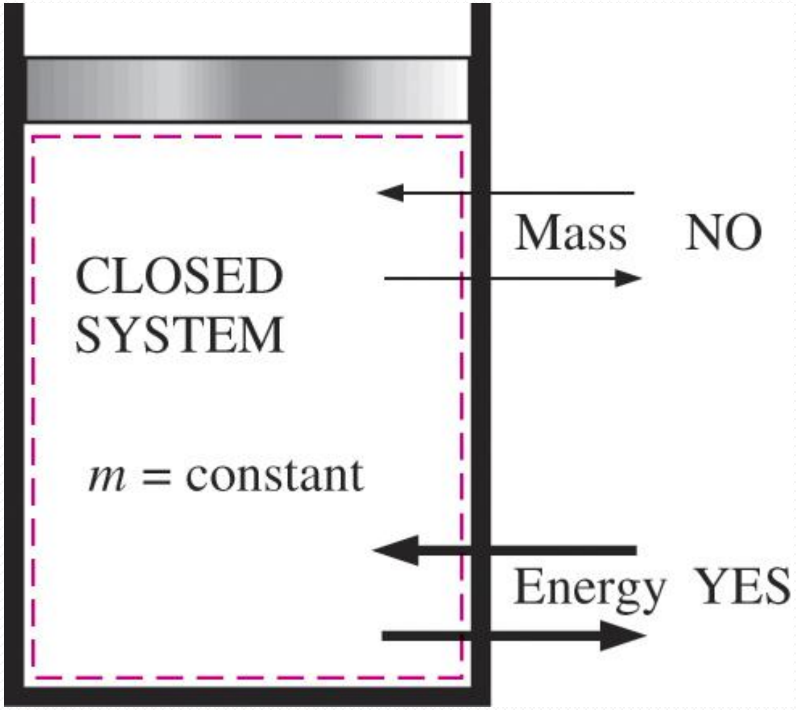
- **System:** **A quantity of matter or a region in space chosen for study.**
- **Surroundings:** **The mass or region outside the system**
- **Boundary:** **The real or imaginary surface that separates the system from its surroundings.**
- **The boundary of a system can be *fixed* or *movable*.**
- **Systems may be considered to be *closed* or *open*.**



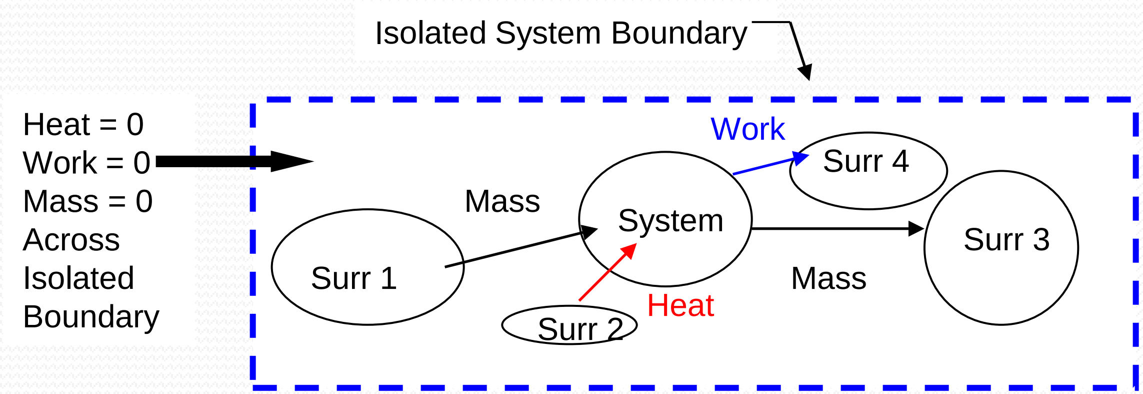


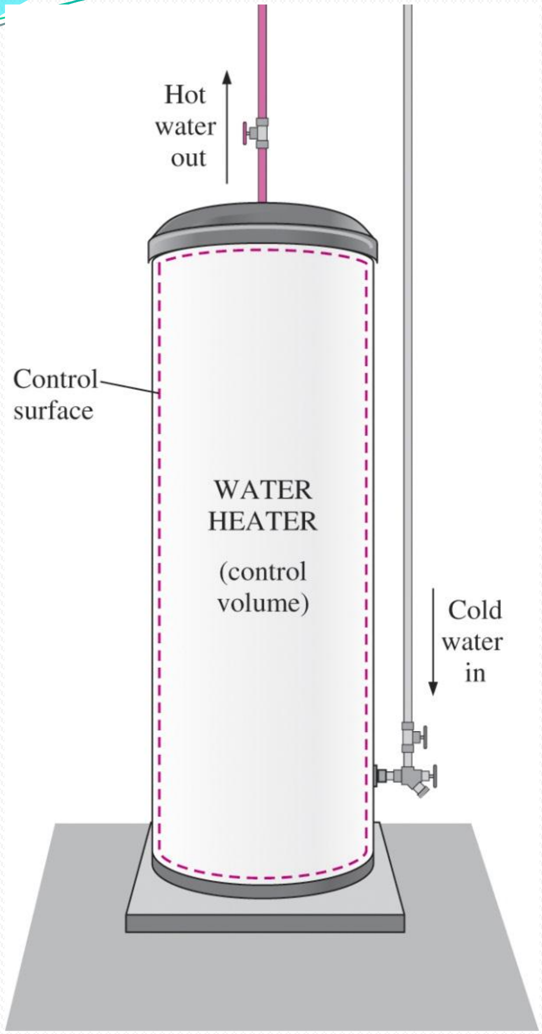
Closed system (Control mass):
A fixed amount of mass, and no mass can cross its boundary.





An **isolated system** is a general system of fixed mass where no heat or work may cross the boundaries. An isolated system is a closed system with no energy crossing the boundaries and is normally a collection of a main system and its surroundings that are exchanging mass and energy among themselves and no other system.

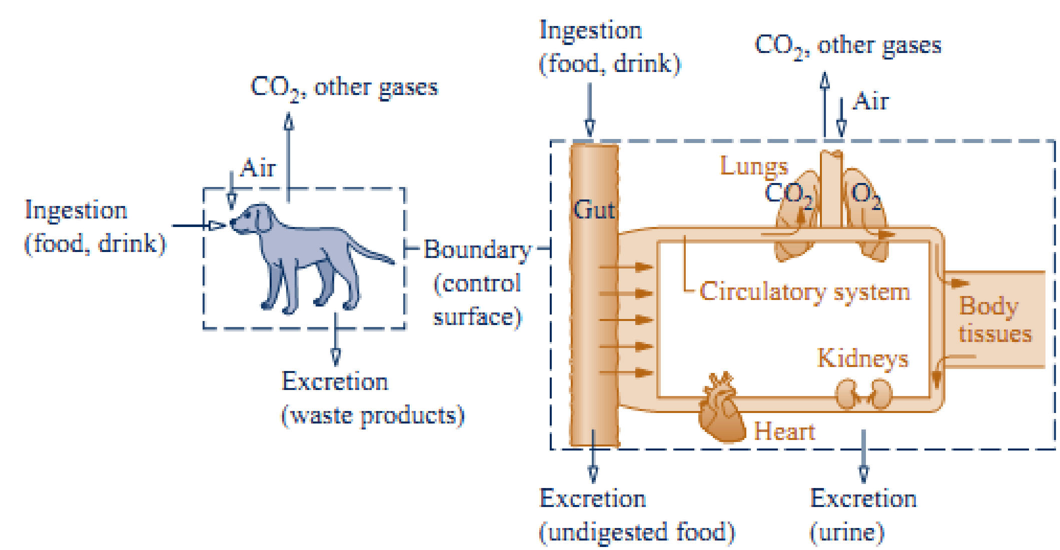




Open system (control volume): A properly selected region in space.

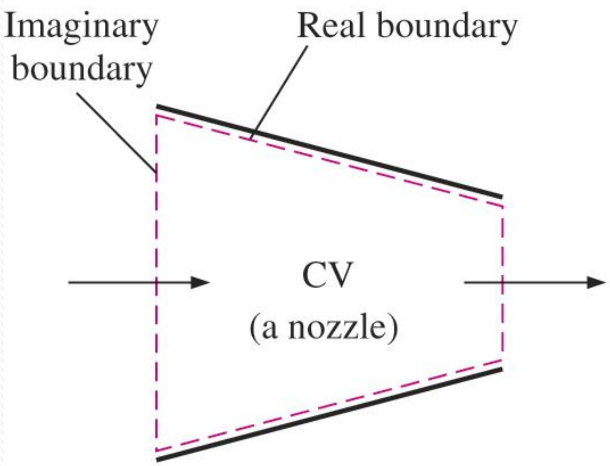
It usually encloses a device that involves mass flow such as a compressor, turbine, or nozzle.

Both mass and energy can cross the boundary of a control volume.

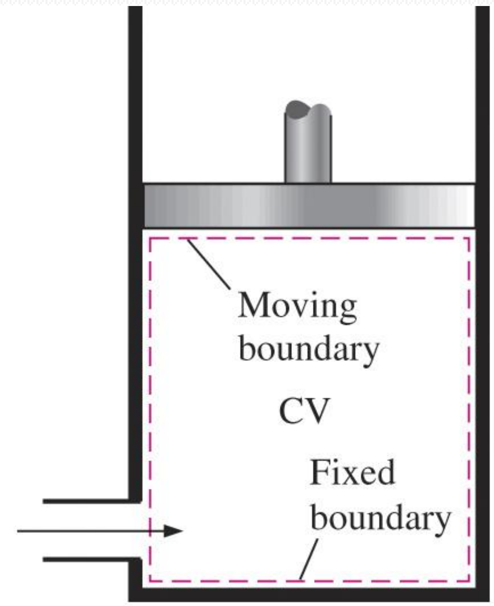


An open system (a control volume) with one inlet and one exit.

Control surface: **The boundaries of a control volume. It can be real or imaginary.**

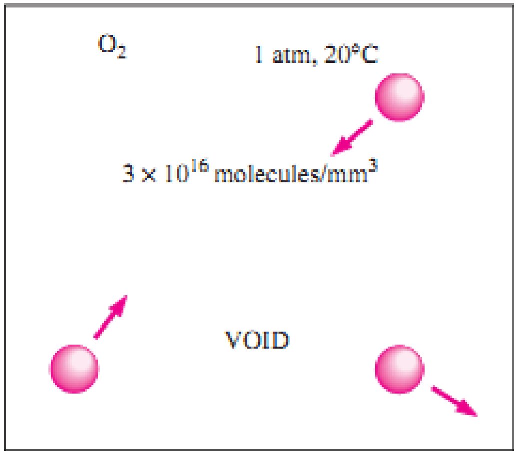


(*a*) A control volume with real and imaginary boundaries



(*b*) A control volume with fixed and moving boundaries

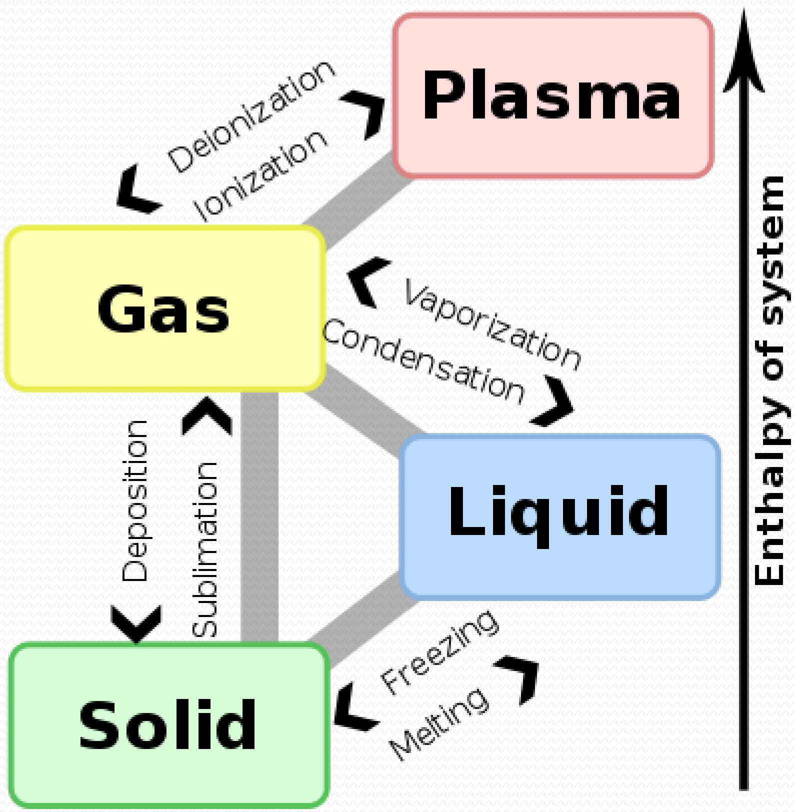
The continuum model is applicable as long as the characteristic length of the system (such as its diameter) is much larger than the mean free path of the molecules.



$$Kn = \frac{Average\ distance\ traveled\ by\ molecules\ between\ collisions\ (mean\ free\ path)}{Characteristic\ dimension\ of\ the\ flow\ field}$$

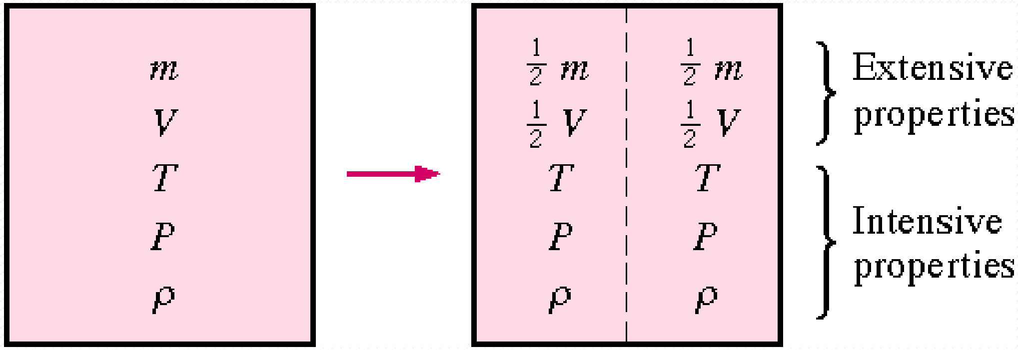
Continuum is known to be valid for $Kn<0.01$.
In this course we will always treat fluids as continuum
The continuum idealization allows us to treat properties as point functions.

Phase and State



PROPERTIES OF A SYSTEM

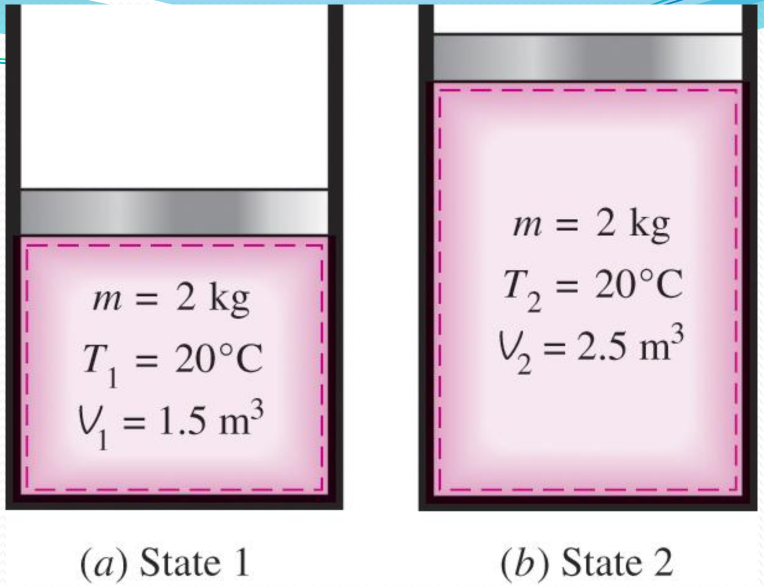
- **Property:** Any characteristic of a system.
- Some familiar properties are pressure *P*, temperature *T*, volume *V*, and mass *m*.
- Properties are considered to be either *intensive* or *extensive*.
- **Intensive properties:** Those that are independent of the mass of a system, such as temperature, pressure, and density.
- **Extensive properties:** Those whose values depend on the size—or extent—of the system.
- **Specific properties:** Extensive properties per unit mass.



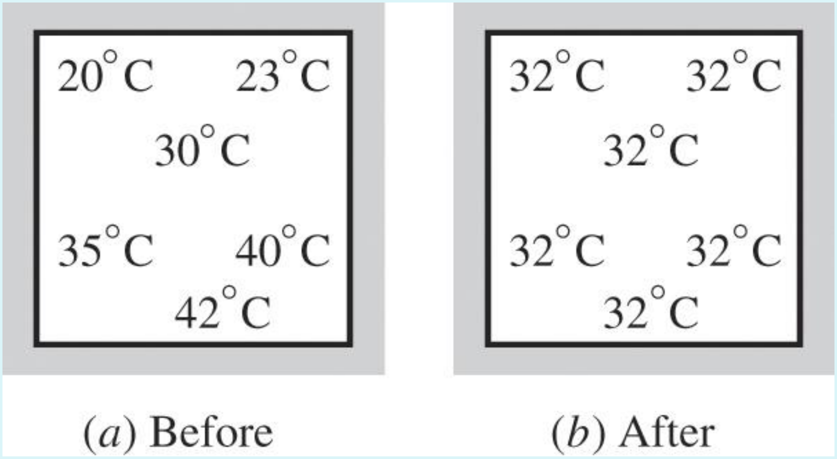
Criterion to differentiate intensive and extensive properties.

STATE AND EQUILIBRIUM

- Thermodynamics deals with *equilibrium* states.
- **Equilibrium**: A 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 system at two different states.



A closed system reaching thermal equilibrium.

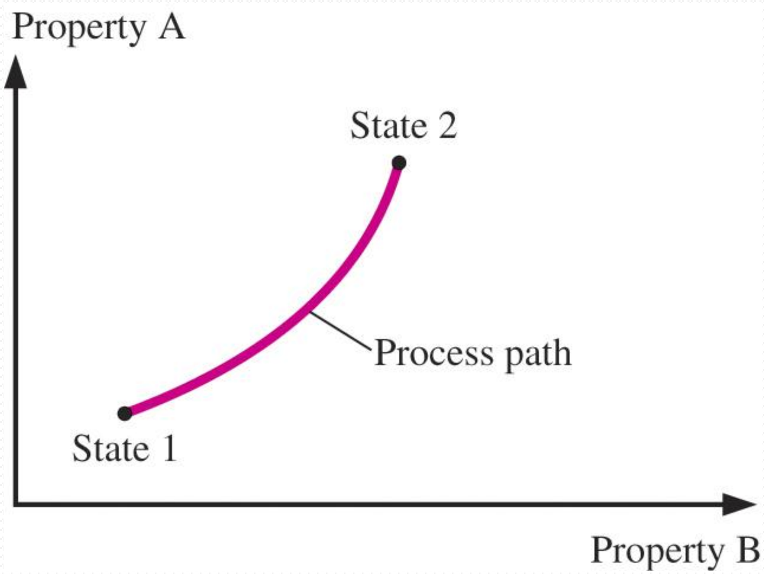
PROCESSES AND CYCLES

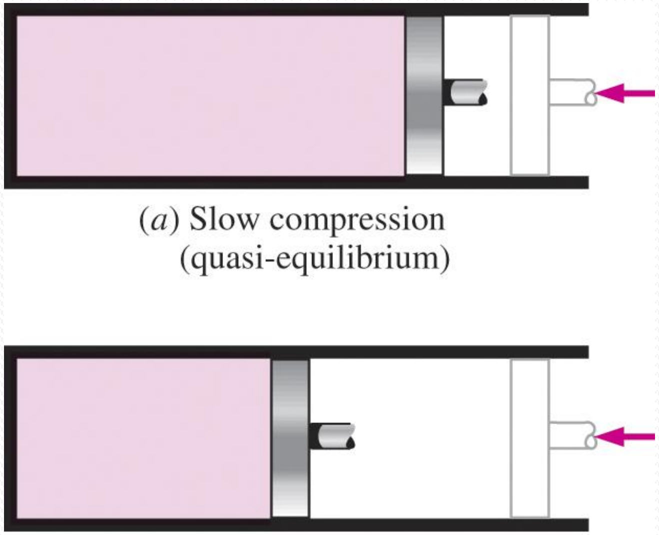
Process: Any change that a system undergoes from one equilibrium state to another.

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.

Quasistatic or quasi-equilibrium process: When a process proceeds in such a manner that the system remains infinitesimally close to an equilibrium state at all times.





(*a*) Slow compression (quasi-equilibrium)

(*b*) Very fast compression (nonquasi-equilibrium)

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

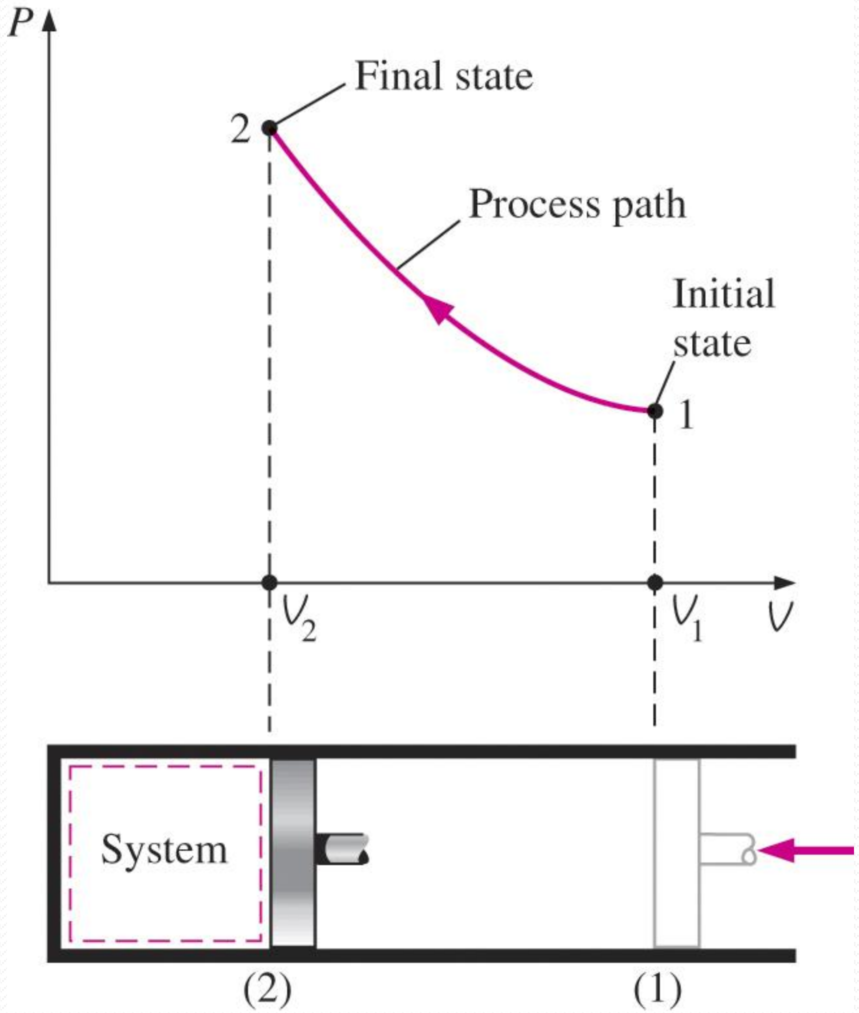
Process	Property held constant
isobaric	pressure
isothermal	temperature
isochoric	volume
isentropic	entropy (see Chapter 7)

Isobaric process: A process during which the pressure *P* remains constant.

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

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

Cycle: A process during which the initial and final states are identical.



The *P-V* diagram of a compression process.

The State Postulate

- The number of properties required to fix the state of a system is given by the **state postulate**:
  - *The state of a simple compressible system is completely specified by two independent, intensive properties.*
- **Simple compressible system:** If a system involves no electrical, magnetic, gravitational, motion, and surface tension effects.

The state of nitrogen is fixed by two independent, intensive properties.

UNITS FOR MASS, LENGTH, TIME, AND FORCE

	SI	USCS	Slug
Mass	Kilogram (kg)	Pound-mass (lbm)	Slug-mass (slug)
Time	Second (s)	Second (s)	Second (s)
Length	Meter (m)	Foot (ft)	Foot (ft)
Force	Newton (N)	Pound-force (lbf)	Pound-force (lbf)

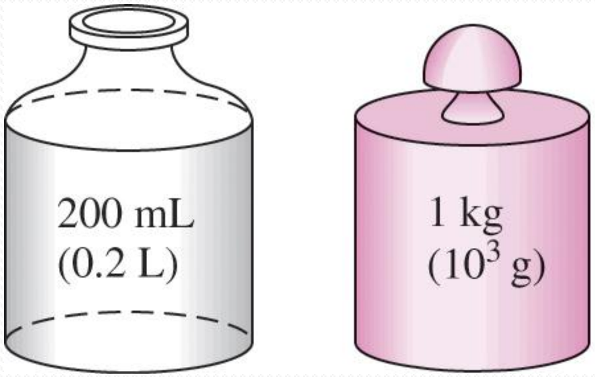
Unit Prefixes

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

Some SI and English Units

$$1 \text{ lbm} = 0.45359 \text{ kg}$$

$$1 \text{ ft} = 0.3048 \text{ m}$$



Work = Force × Distance

$1 \text{ J} = 1 \text{ N·m}$

$1 \text{ cal} = 4.1868 \text{ J}$

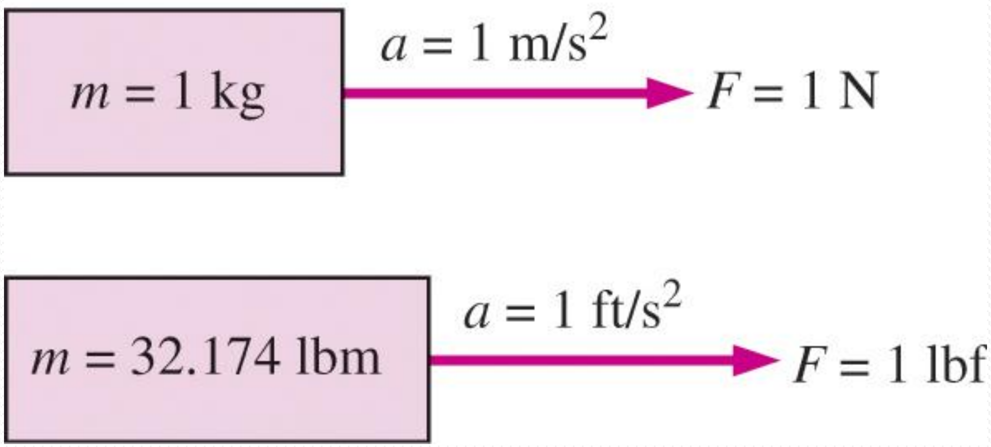
$1 \text{ Btu} = 1.0551 \text{ kJ}$

$$\text{Force} = (\text{Mass})(\text{Acceleration})$$

$$F = ma$$

$$1 \text{ N} = 1 \text{ kg} \cdot \text{m/s}^2$$

$$1 \text{ lbf} = 32.174 \text{ lbm} \cdot \text{ft/s}^2$$



The definition of the force units.

Energy

We have no knowledge of what energy is.. it is an abstract thing….

Energy comes in many interconvertible forms

- internal (atomic motion in solids, liquids & gases)
- electrical & magnetic
- chemical - in molecular bonds (coal power)
- kinetic (wind power)
- potential – gravitational (hydropower)
- radiant (solar power)
- nuclear – in proton-neutron bonds (nuclear power)

and their sum constitutes the **total energy, *E*** of a system.

FORMS OF ENERGY

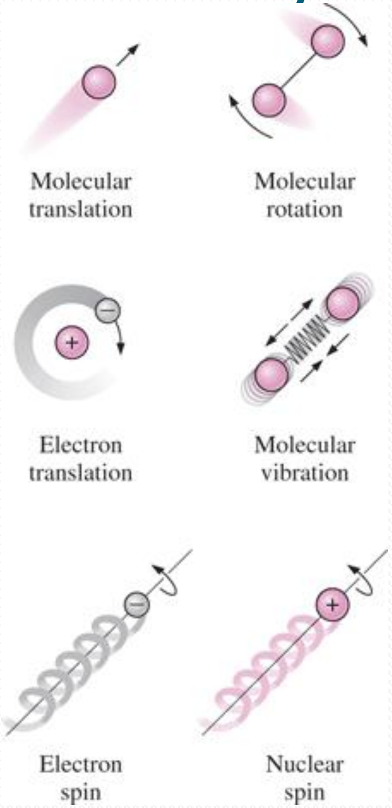
- Thermodynamics deals only with the ***change*** of the total energy.
- **Macroscopic forms of energy**: Those a system possesses as a whole with respect to some outside reference frame, such as kinetic and potential energies.
- **Microscopic forms of energy**: Those related to the molecular structure of a system and the degree of the molecular activity.
- **Internal energy, *U***: The sum of all the microscopic forms of energy.

Kinetic energy, KE: The energy that a system possesses as a result of its motion relative to some reference frame.

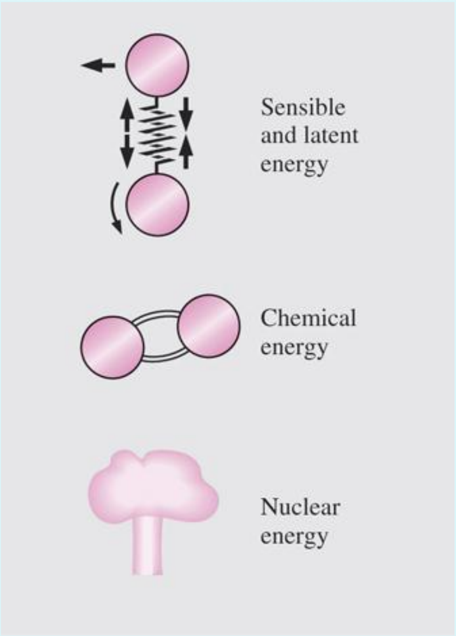
Potential energy, PE: The energy that a system possesses as a result of its elevation in a gravitational field.

The macroscopic energy of an object changes with velocity and elevation.

Some Physical Insight to Internal Energy



The various forms of microscopic energies that make up *sensible* energy.



The internal energy of a system is the sum of all forms of the microscopic energies.

Sensible energy: The portion of the internal energy of a system associated with the kinetic energies of the molecules.

Latent energy: The internal energy associated with the phase of a system.

Chemical energy: The internal energy associated with the atomic bonds in a molecule.

Nuclear energy: The tremendous amount of energy associated with the strong bonds within the nucleus of the atom itself.

Thermal = Sensible + Latent

Internal = Sensible + Latent + Chemical + Nuclear

DENSITY AND SPECIFIC GRAVITY

Density

$$\rho = \frac{m}{V} \qquad (\text{kg/m}^3)$$

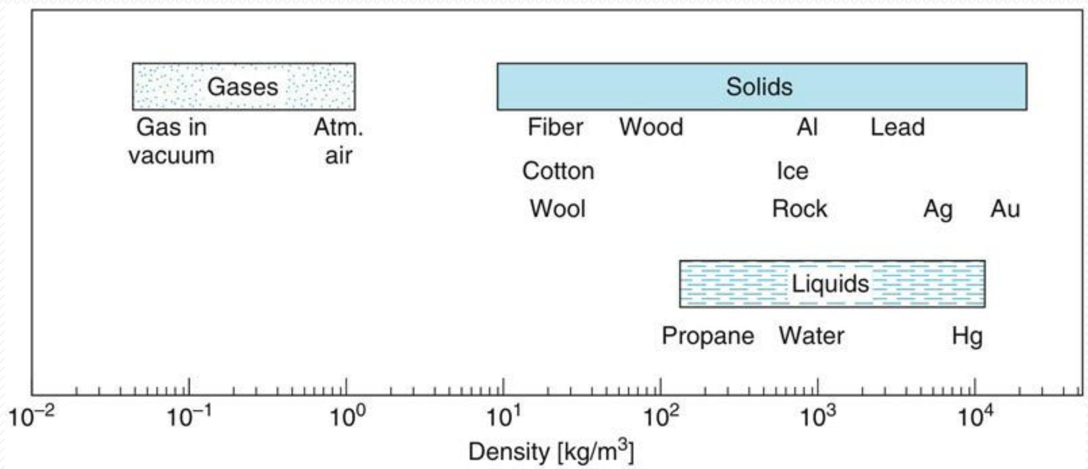
Specific volume

$$v = \frac{V}{m} = \frac{1}{\rho}$$

$$V = 12 \text{ m}^3$$
$$m = 3 \text{ kg}$$
$$\downarrow$$
$$\rho = 0.25 \text{ kg/m}^3$$
$$v = \frac{1}{\rho} = 4 \text{ m}^3/\text{kg}$$

Density is mass per unit volume; specific volume is volume per unit mass.

Density of common substances



PRESSURE

Pressure: A normal force exerted by a fluid per unit area

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

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

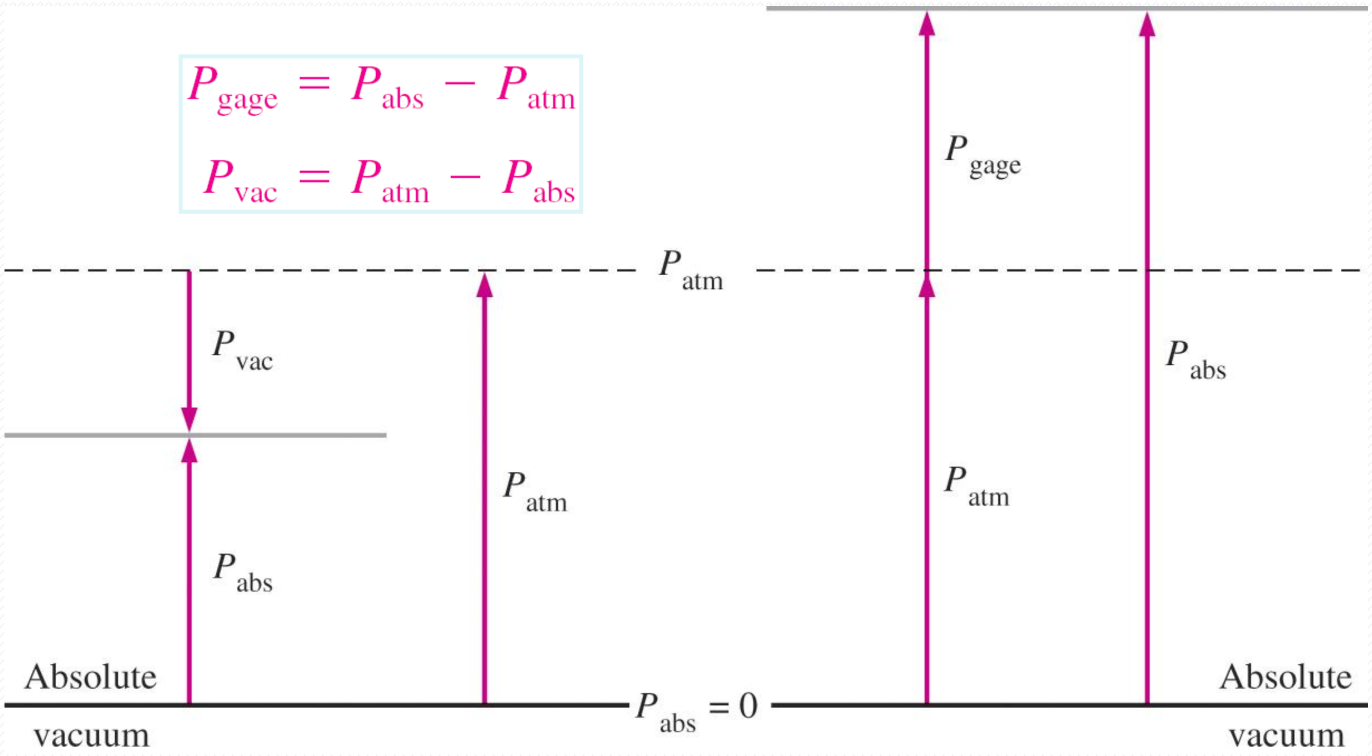
$1 \text{ atm} = 101.325 \text{ kPa} = 14.696 \text{ lbf/in}^2$ (= psi)

Some basic pressure gages.

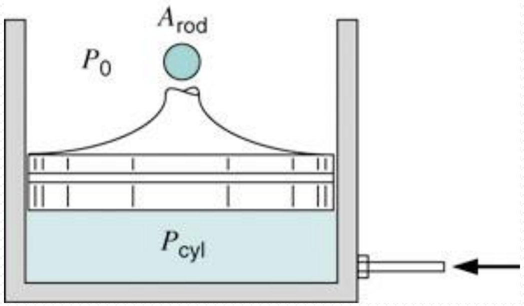
- **Absolute pressure**: The actual pressure at a given position. It is measured relative to absolute vacuum (i.e., absolute zero pressure).
- **Gage pressure**: The difference between the absolute pressure and the local atmospheric pressure. Most pressure-measuring devices are calibrated to read zero in the atmosphere, and so they indicate gage pressure.
- **Vacuum pressures**: Pressures below atmospheric pressure.

$$P_{gage} = P_{abs} - P_{atm}$$

$$P_{vac} = P_{atm} - P_{abs}$$



The hydraulic piston/cylinder system shown in Figure has a cylinder diameter of *D* = 0.1 m with a piston and rod mass of 25 kg. The rod has a diameter of 0.01 m with an outside atmospheric pressure of 101 kPa. The inside hydraulic fluid pressure is 250 kPa. How large a force can the rod push within the upward direction?



$$F_{net} = ma = 0$$

$$= P_{cyl} A_{cyl} - P_o (A_{cyl} - A_{rod}) - F - m_P g$$

solve for F $\quad F = P_{cyl} A_{cyl} - P_o (A_{cyl} - A_{rod}) - m_P g$

The areas are:

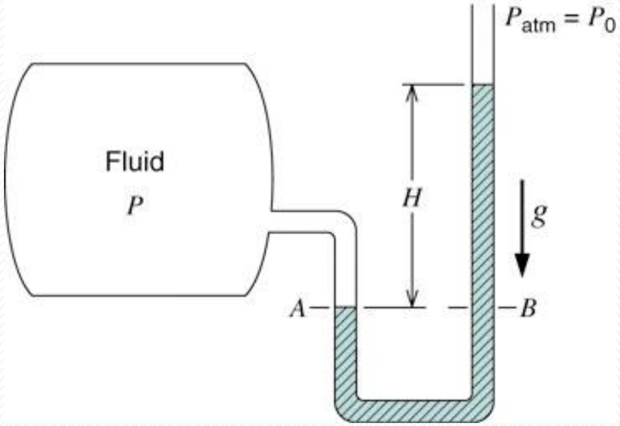
$$A_{cyl} = \frac{\pi}{4} d^2 = \frac{\pi}{4} 0.1^2 = 0.007854 m^2 \qquad A_{rod} = \frac{\pi}{4} 0.001^2 = 0.00007854 m^2$$

So the force becomes $\quad F = [250 * 0.007854 - 101 * (0.007854 - 0.00007854)] *$

$$1000 - 25 * 9.81 = 1963.5 - 785.32 - 245.25$$

$$= 932.9 N$$

Note that we must convert kPa to Pa to get units of N.



The force acting downward at the bottom of the column is

$$P_o A + mg = P_o A + \rho A g H$$

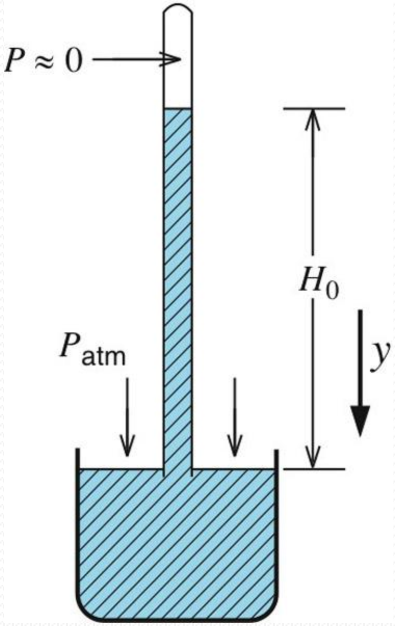
This force must be balanced by the upward force at the bottom of the column, which is $P_B A$. Therefore,

$$P_B - P_o = \rho g H$$

Since points A and B are at the same elevation in columns of the same fluid, their pressures must be equal

Equation A $$\Delta P = P - P_o = \rho g H$$

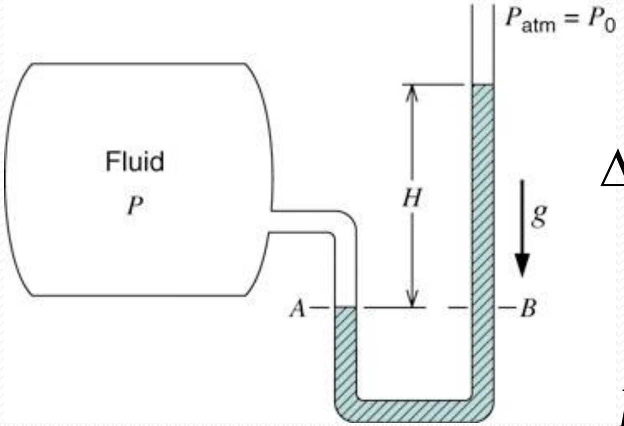
(the fluid being measured in the vessel has a much lower density, such that its pressure P is equal to P_A)



Consider the barometer used to measure atmospheric pressure, Since there is a near vacuum in the closed tube above the vertical column of fluid, usually mercury, the height of the column gives the atmospheric pressure

$$P_{atm} = \rho g H_0$$

A mercury (Hg) manometer is used to measure the pressure in a vessel as shown in Figure. The mercury has a density of 13 590 kg/m^3, and the height difference between the two columns is measured to be 24 cm. We want to determine the pressure inside the vessel.



The manometer measures the gauge pressure as a pressure difference

$$\Delta P = P_{gage} = \rho g H = 13590 * 9.806 * 0.24 = 31.985 kPa$$

To get the absolute pressure inside the vessel we have

$$P_A = P_{vessel} = P_B = \Delta P + P_{atm}$$

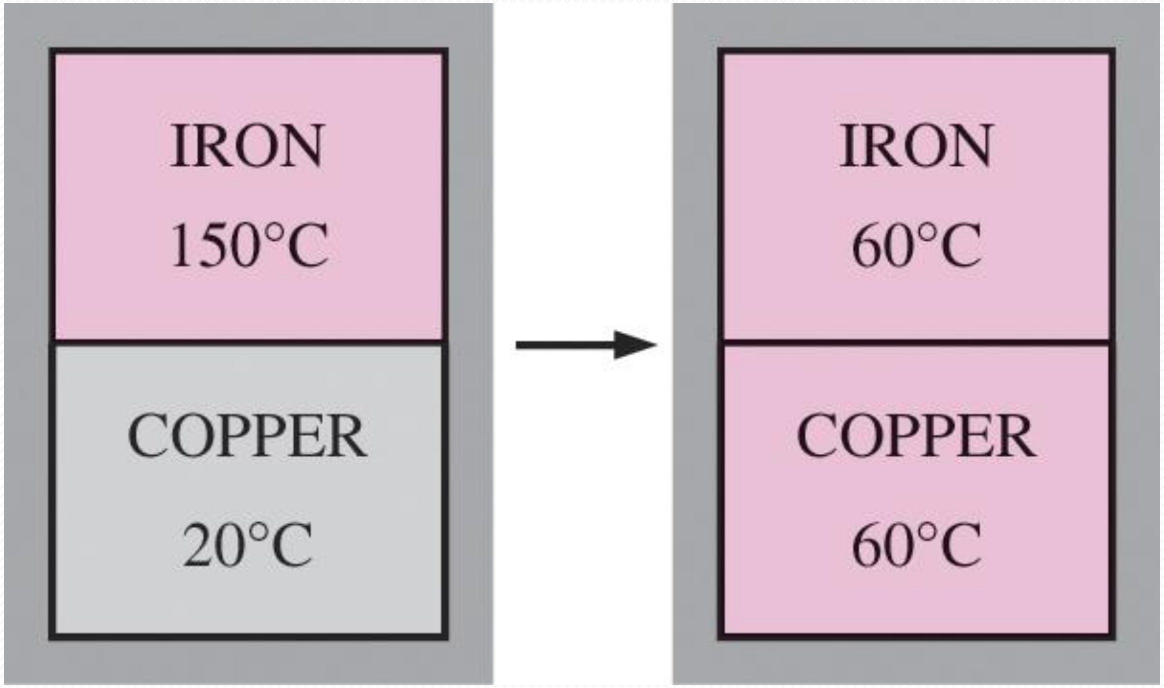
The absolute pressure in the vessel become

$$P_{vessel} = \Delta P + P_{atm} = 32985 + 13590 * 0.75 * 9.806$$

$$P_{vessel} = \Delta P + P_{atm} = 31985 + 99954 = 131940\, Pa = 1.302\, atm$$

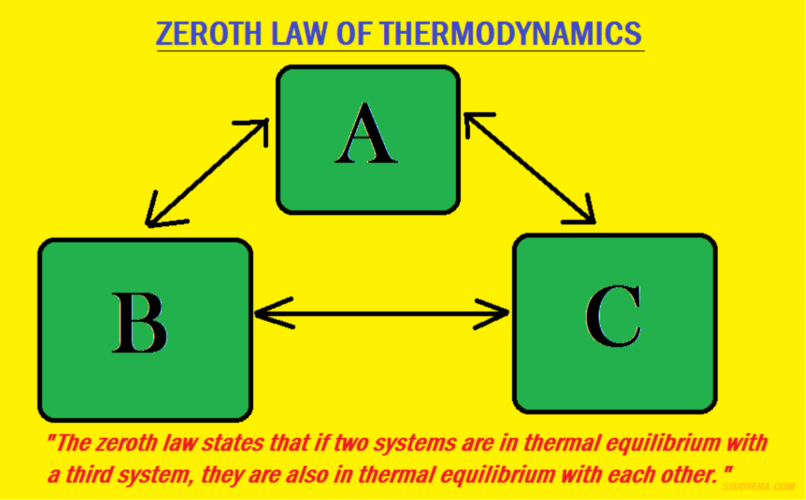
Equality of Temperature

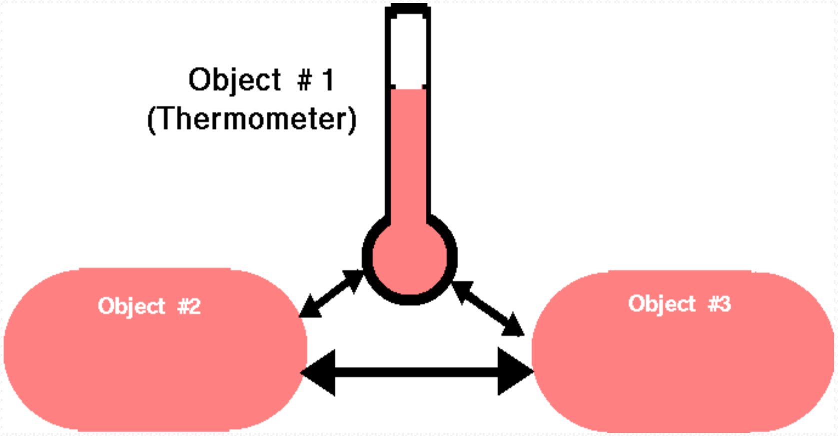
Two bodies reaching thermal equilibrium after being brought into contact in an isolated enclosure.



The Zeroth Law of Thermodynamics

- **The zeroth law of thermodynamics**: If two bodies are in thermal equilibrium with a third body, they are also in thermal equilibrium with each other.
- By replacing the third body with a thermometer, the zeroth law can be restated as *two bodies are in thermal equilibrium if both have the same temperature reading even if they are not in contact*.

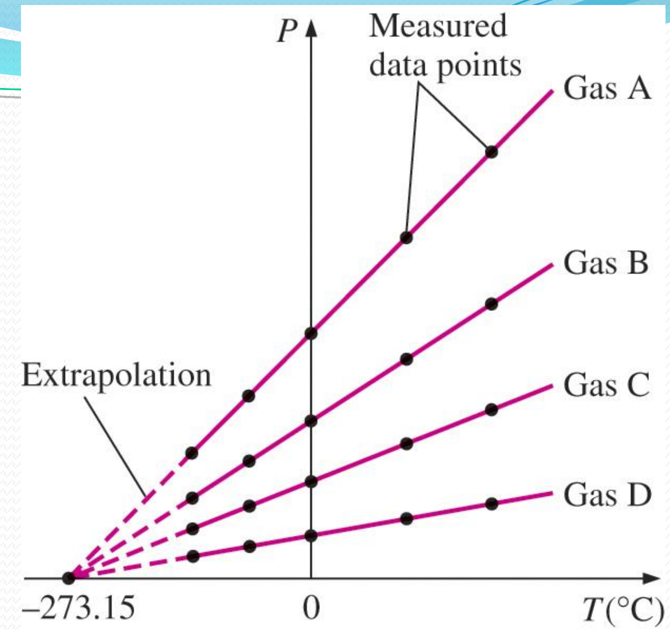


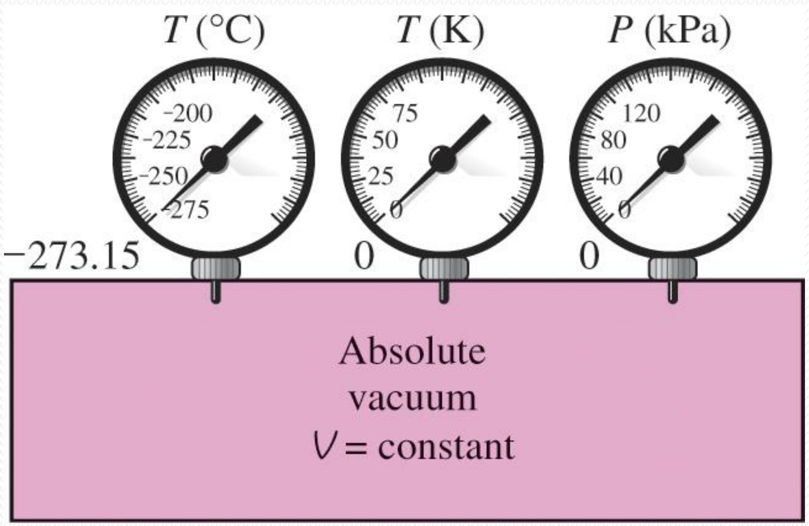


Temperature Scales

- All temperature scales are based on some easily reproducible states such as the freezing and boiling points of water: the *ice point* and the *steam point.*
- **Celsius scale**: in SI unit system
- **Fahrenheit scale**: in English unit system
- **Kelvin scale** (SI)
- **Rankine scale** (E)

P versus *T* plots of the experimental data obtained from a constant-volume gas thermometer using four different gases at different (but low) pressures.





A constant-volume gas thermometer would read -273.15°C at absolute zero pressure.

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

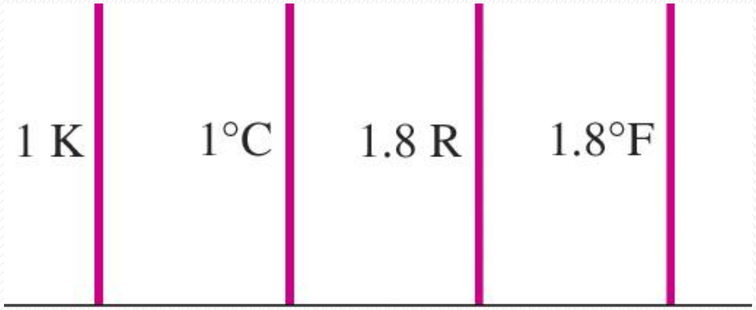
$$T(\mathrm{R}) = T(^\circ\mathrm{F}) + 459.67$$

$$T(\mathrm{R}) = 1.8T(\mathrm{K})$$

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

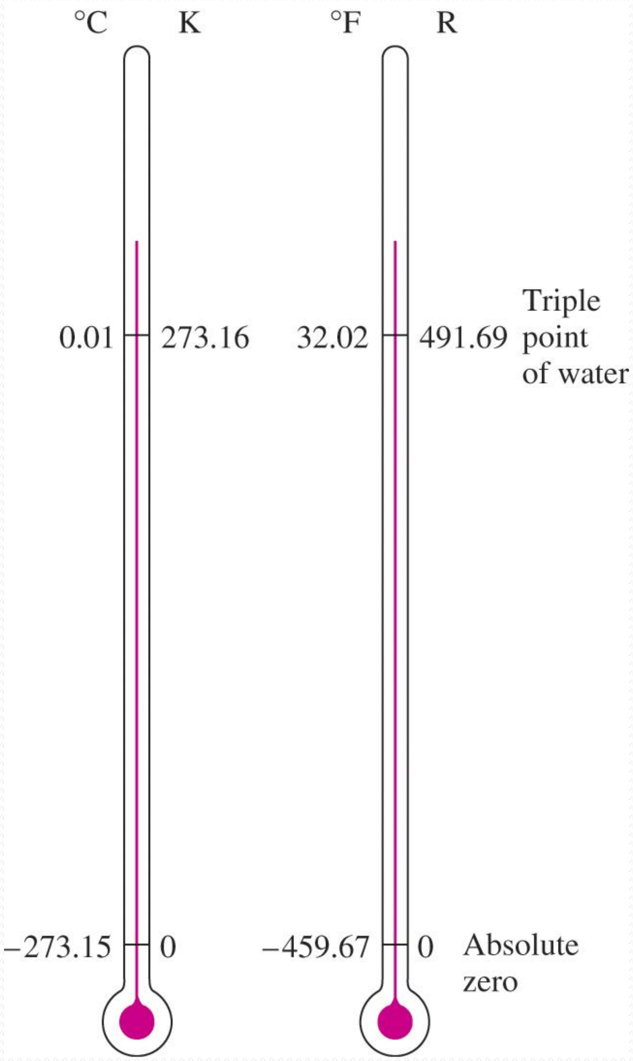
$$\Delta T(\mathrm{K}) = \Delta T(^\circ\mathrm{C})$$

$$\Delta T(\mathrm{R}) = \Delta T(^\circ\mathrm{F})$$

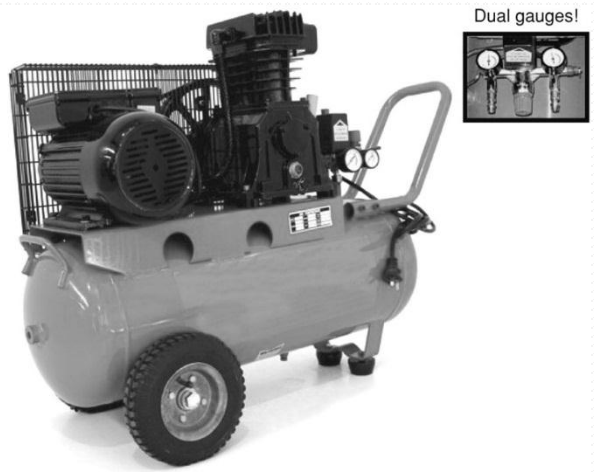


Comparison of magnitudes of various temperature units.

Comparison of temperature scales.

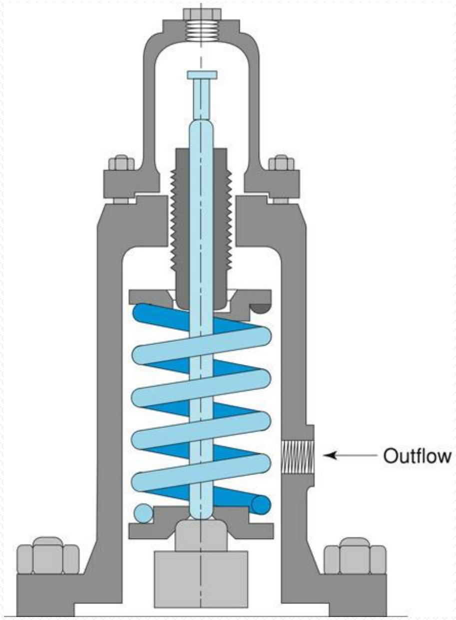


Engineering Applications

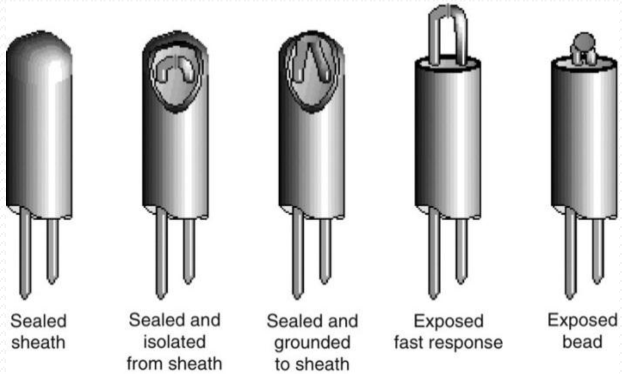


Air compressor with tank

Automotive tire pressure gages



Schematic of a pressure relief valve



Thermocouples