LECTURE # 1

Chapter 1 (Session #1):

Introduction and Basic Concepts

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Chapter 1: Introduction and Basic Concepts

Outcomes:

- Define & Explain the basic concepts of thermodynamics
  - **Examples:** system, state, state postulate, equilibrium, process, and cycle.
- Understand concepts of temperature, temperature scales; pressure, and absolute and gage pressure.
- Understand and use the metric (SI) unit system.

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What is Thermodynamics?

- **Science dealing with:**
  - Energy and its transformations
  - Relationships between the properties of substances
- Rooted in Experimental Observations & Definitions

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What is Energy?

- **Capacity, either latent or apparent, to exert a force through a distance**
- **Capacity to produce change**
  - has many forms -- can be converted from naturally occurring to desired forms
  - Automobile changes gasoline to motion; power plant changes coal to electricity; winch uses electricity to hoist an object; etc.

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THERMODYNAMIC LAWS

- **State Postulate**
  - Properties of matter are functionally related
- **First Law -- Conservation of Energy**
  - Energy cannot be created or destroyed
- **Second Law -- “Quality” of Energy**
  - Governs direction of heat flow (hot to cold) & extent to which thermal energy (“heat”) can be converted to mechanical energy (“work”)

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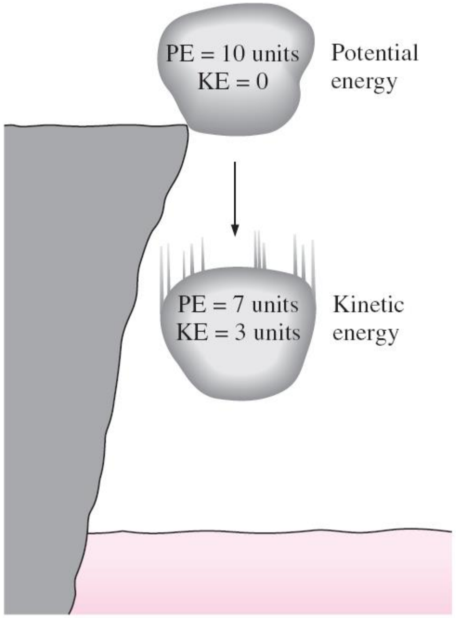
Conservation of Energy



Conservation of energy principle (The First Law):

- Energy can be changed from one form to another but the total amount of energy remains constant.
- Energy cannot be created or destroyed.
- The first law implies that *energy* is a Thermodynamic property.

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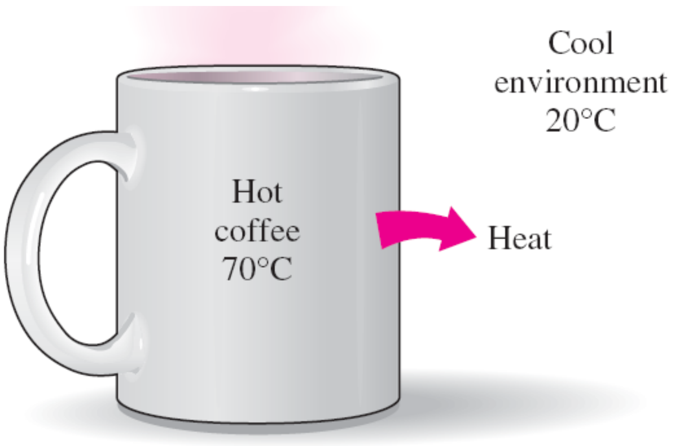
The Second Law

- **The second law of Thermodynamics** asserts that energy has *quality* as well as *quantity*, and that actual processes occur in the direction of decreasing quality of energy.



Heat **by itself** flows only in the direction of decreasing temperature.

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THERMODYNAMIC LAWS

- **Where do these laws come from?**

- **Fundamental Laws of Nature**
  - Their truth rests on the fact that in all of our human experience, no system has ever been found which violates them

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Classical versus Statistical Thermodynamics

- **Classical Thermodynamics**
  - Deals with "macroscopic behavior" of matter
    - does not deal with events at molecular level
    - provides a direct and easy way to the solution of engineering problems
- **Statistical Thermodynamics**
  - Kinetic theory & statistical mechanics
    - Deals with "micro structure"
    - Predicts average behavior of large number of molecules
- **Only Classical Thermodynamics will be studied in this course**

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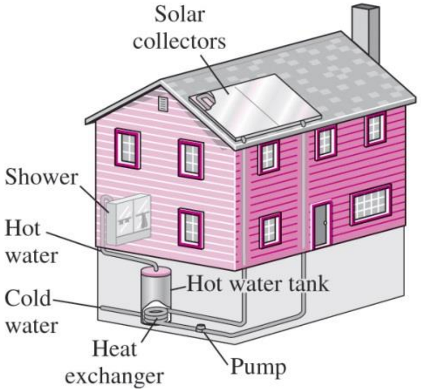
RELEVANCE TO ME
Applications of Thermodynamics







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RELEVANCE TO ME
Applications of Thermodynamics

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HEAT TRANSFER

- **Subject dealing with Energy "in transit" due to a temperature difference**
- **Three "Modes" of heat transfer**
  - Conduction
  - Convection
  - Radiation

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Heat Transfer Modes

- **Conduction**
  - Due to temperature gradient in a stationary medium (solid or fluid)
- **Convection**
  - Due to temperature difference between a surface and a moving fluid
- **Radiation**
  - Electromagnetic waves emitted by surfaces

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Difference Between Heat Transfer & Thermodynamics

- **Thermodynamics deals with relation between "equilibrium" states of a system**
  - Example: Cooling of a hot object -- amount of heat transferred between initial and final conditions
  - No indication of "how long" it will take
- **Heat Transfer deals with heat exchange within a non-equilibrium system**
  - Determine the "rate" of heat exchange -- How long will the process take?

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LECTURE # 2

Chapter 1 (Session #2):

Introduction and Basic Concepts

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DIMENSIONS & UNITS

- Any physical quantity can be characterized by a **unique** set of **dimensions**.

- The magnitudes assigned to the dimensions are called **units**.
  - The same physical quantity can be given in different units [e.g. person is 1.83 m (or 183 cm; or 6 feet) tall]

- Will use the International System of Units **(SI)** throughout the course.
  - Text uses both SI and British Units

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DIMENSIONS & UNITS

- There are seven **primary** or **fundamental dimensions.** **ME's deal mostly with four fundamental dimensions:**
  - Length (L); Mass (M); Time (t); and Temperature (T)
  - Corresponding units are meter; kilogram; second; and kelvin.

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)

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Derived Dimensions & Units

- **Use definitions & physical relations to "derive" dimensions & units of other physical quantities**
  - Examples:
    - Velocity ≡ L/t (m/s)
    - Acceleration ≡ d V/dt ≡ (L/t)/t ≡ L/t^2 (m/s^2)
    - Force = mass x acceleration ≡ ML/t^2 (kg m/s^2) ≡ N
    - Work (Energy) ≡ Force x distance ≡ ML^2/t^2 (N.m)
      1 joule = 1 (newton.meter) = 1 (kg m^2/s^2)

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Standard Prefixes in SI Units

- Examples:
  - 1 cm = 10^{-2} m
  - 1 kg = 10^3 g
  - 1 ms = 10^{-3} s
  - 1 μK = 10^{-6} K
  - 1 MJ = 10^6 J

TABLE 1–2

Standard prefixes in SI units

Multiple	Prefix
10^{12}	tera, T
10^{9}	giga, G
10^{6}	mega, M
10^{3}	kilo, k
10^{2}	hecto, h
10^{1}	deka, da
10^{-1}	deci, d
10^{-2}	centi, c
10^{-3}	milli, m
10^{-6}	micro, μ
10^{-9}	nano, n
10^{-12}	pico, p

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Dimensional Homogeneity

- **All correct equations must be dimensionally homogeneous.**
- **To be dimensionally homogeneous, all terms in an equation must have the same units (i.e. same dimensions)**
  - A dimensionally inhomogeneous equation is **definitely** wrong [Example: Sphere Volume = πR^2]
  - A dimensionally homogeneous equation is not necessarily correct [Example: Sphere Volume = $5 \pi R^3$]

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DEFINITIONS

- ***System:*** "A quantity of matter or a region in space chosen for study."
- ***Surroundings:*** "Matter or region outside the system."
- ***Boundary:*** "Real or imaginary surface that separates the system from its surroundings."

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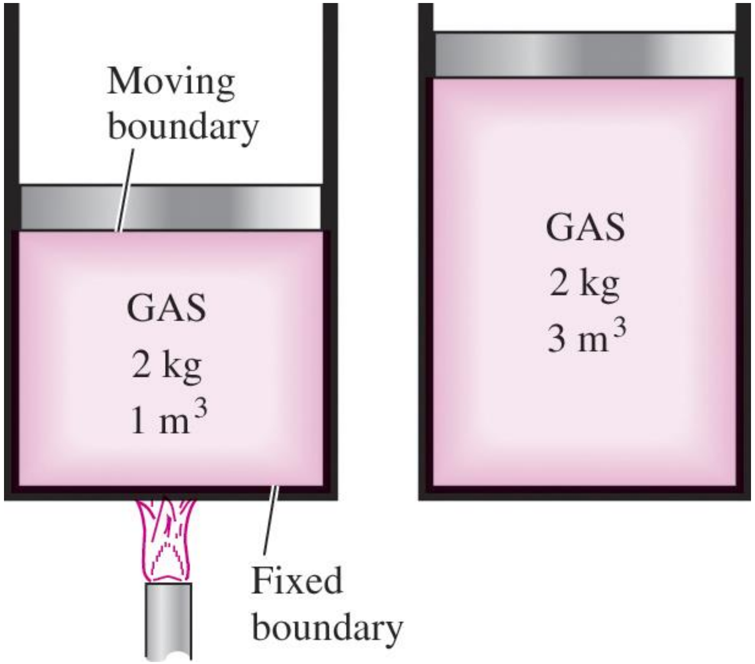
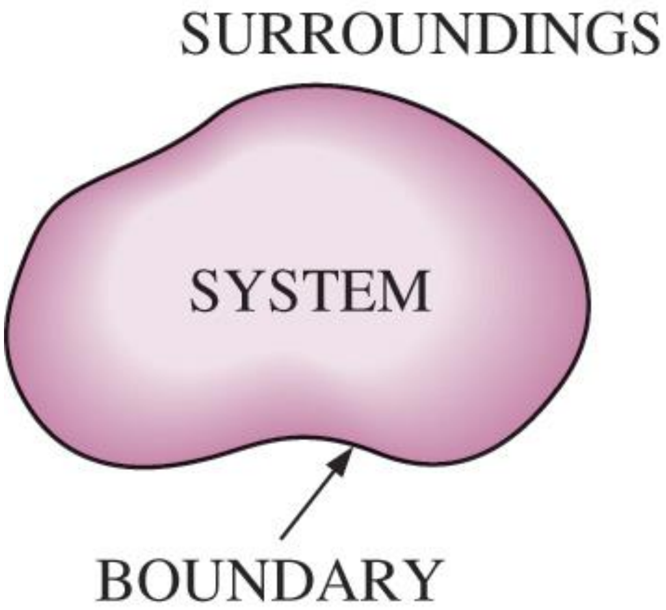
System, Surroundings & Boundary





- The boundary of a system can be *fixed* or *movable*.
- Systems may be considered to be *closed* or *open*.

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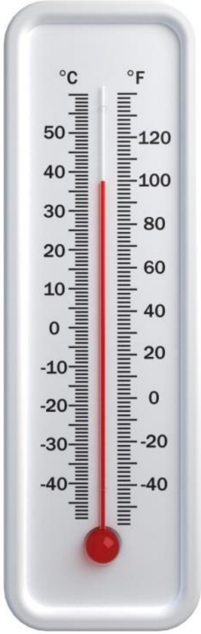
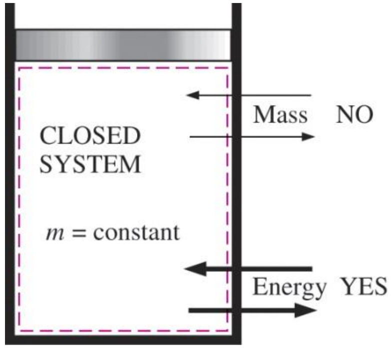
CLOSED SYSTEM (Control Mass)

- ❑ **Region of constant mass – Only energy can cross its boundary**
  - ➢ Boundary may be fixed or moving
- ❑ **Special Case: *"Isolated System"***
  - ➢ Neither mass nor energy can cross its boundary
  - ➢ Boundary of isolated system must be fixed





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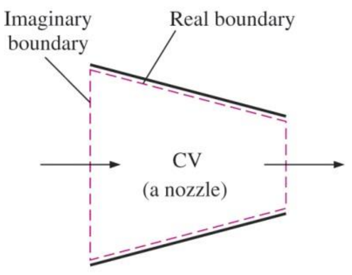
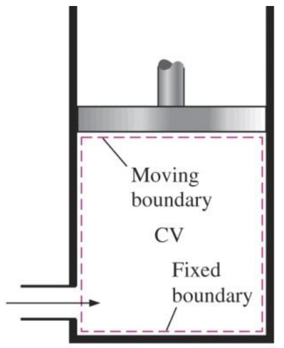
OPEN SYSTEM (Control Volume)

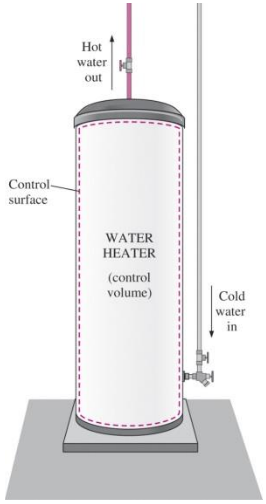
- Region in space where both mass and energy may cross its boundary
  - **Examples:** turbine; compressor; water heater; nozzle; jet engine; etc.
    - Mass within the system is not necessarily constant
    - Boundary (Control Surface) may be rigid (e.g. nozzle) or moving (e.g. IC engine cylinder)
    - Boundary may be real or imaginary



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



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



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

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DEFINITIONS

- ***Property:*** A characteristic of the system
  - Extensive properties: depend on the size (i.e. "Extent") of the system (e.g. mass, volume, total energy)
    - Extensive properties per unit mass are called "specific properties" (e.g. specific volume, specific total energy)
  - Intensive properties: independent of the size of the system (e.g. pressure, temperature, density; specific volume)

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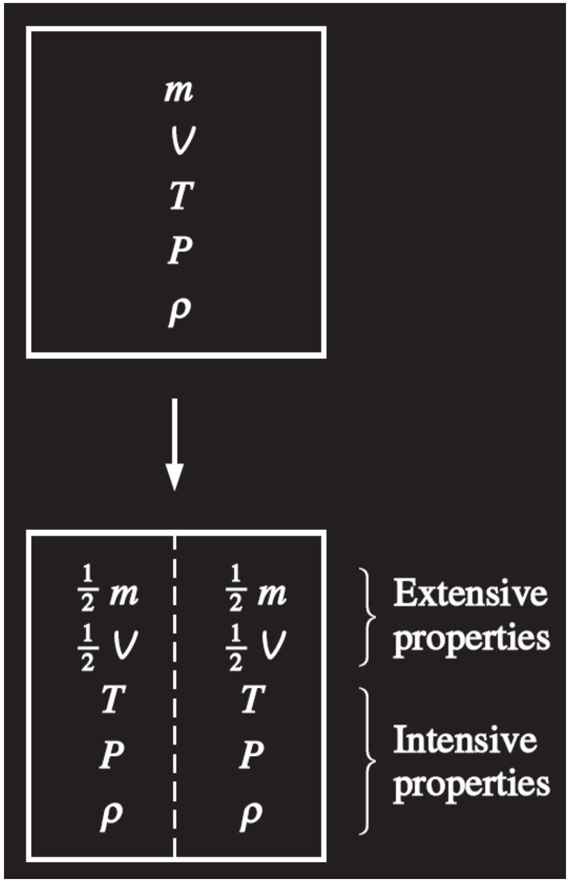
INTENSIVE & EXTENSIVE PROPERTIES

Criterion to differentiate between intensive and extensive properties



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Specific Properties

- **Specific Properties:** Extensive properties per unit mass
  - Specific properties are denoted by lower case letters.
  - **Examples:** specific volume (v); specific energy(e)
  - Specific properties are intensive properties

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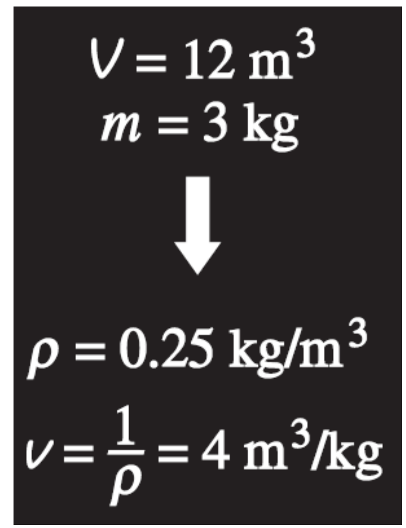
Density & Specific Volume

- ***Density:*** mass per unit volume
  - $\rho = m/V$ (kg/m^3)
- ***Specific volume:*** volume per unit mass
  - $v = V/m = 1/\rho$ (m^3/kg)



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Specific Gravity & Specific Weight

- ***Specific Gravity*** (Relative Density): ratio between density of a substance and density of water at 4 °C ($\rho_{H2O@\,4\,°C}$ = 1000 kg/m^3)
  - SG = ρ/ρ_{H2O} (non-dimensional)
- ***Specific Weight***: weight of a unit volume of a substance
  - $\gamma_s = \rho\, g\, (kg/m^3)\times(m/s^2) = (kg/m^2.\, s^2) = (kg.m/s^2)/m^3$
    $= N/m^3$ [g = gravitational acceleration]

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DEFINITIONS

- ***State:*** Condition of the system at an instant of time as described or measured by its properties

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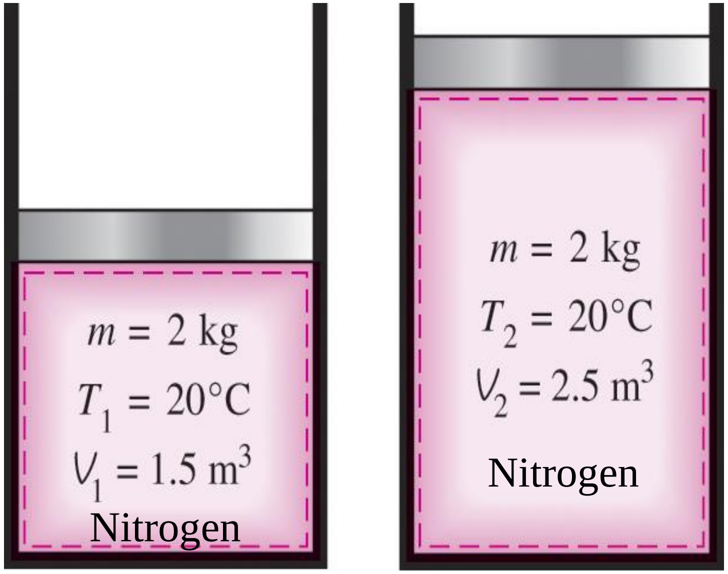
Thermodynamic *"State"* of a System

- Consider a system **not** undergoing any change
- Properties can be measured (or calculated) throughout entire system
- If any of the properties changes, the state of the system changes to a different one



(*a*) State 1 (*b*) State 2

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Thermodynamic "EQUILIBRIUM"

- "Equilibrium" implies a state of "balance"
  - A system in equilibrium experiences no change when isolated from its surroundings
  - Intensive properties are uniform throughout the system - a single set of properties defines the state of the system
- **Thermal, Mechanical, Phase, and Chemical Equilibrium**

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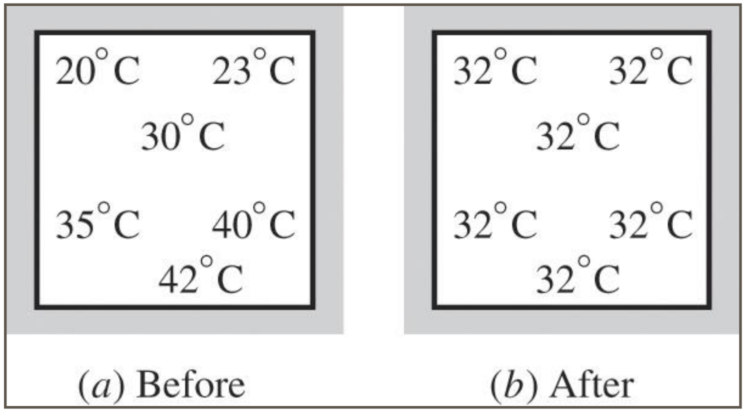
Elements of Thermodynamic Equilibrium

- **Thermal equilibrium**: temperature is the same throughout the entire system
- **Mechanical equilibrium:** there is no change in pressure at any point of the system with time.
- **Phase equilibrium:** for a system consisting of two phases when mass of each phase reaches an equilibrium level and stays there.
- **Chemical equilibrium:** the chemical composition of a system does not change with time, that is, no chemical reactions occur.



A closed system reaching thermal equilibrium.

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The State Postulate

- The properties of matter are functionally related -- **Do not need to specify all properties to fix a state**
- The equilibrium state of a simple system is completely specified **by any two independent intensive properties**
  - "Simple" = no electrical, magnetic, motion, gravitational, or surface tension effects

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Examples -- Suitable Properties?

- Mass & Pressure [**No**; mass is extensive]
- Density & specific volume [**No**; $v = 1/\rho$; not independent]
- Pressure & specific volume [**yes**]
- Temperature & specific volume [**yes**]
- Pressure & temperature [**yes** for single phase; **No** during phase change T = T(P)]

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Example – Equilibrium State of a Simple System

The state of nitrogen is fixed by two independent, intensive properties – in this case Temperature and Specific Volume.

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Question

- If we know two independent intensive properties (for a given state), how do we determine the rest of the properties?
- **"Equation of state"** A relationship between properties
  - Example "ideal Gas": $P\,v = R\,T$
- How about water, refrigerants, etc. ?
  - Pure substances (will discuss in Chapter 3)

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Thermodynamic "Process"

- **System undergoes change from one equilibrium state to another**
- Process **"path"** is the series of states through which the system passes between the "initial" and "final" equilibrium states
- **"Quasi-equilibrium process"** = extremely slow process; system passes through a sequence of equilibrium states

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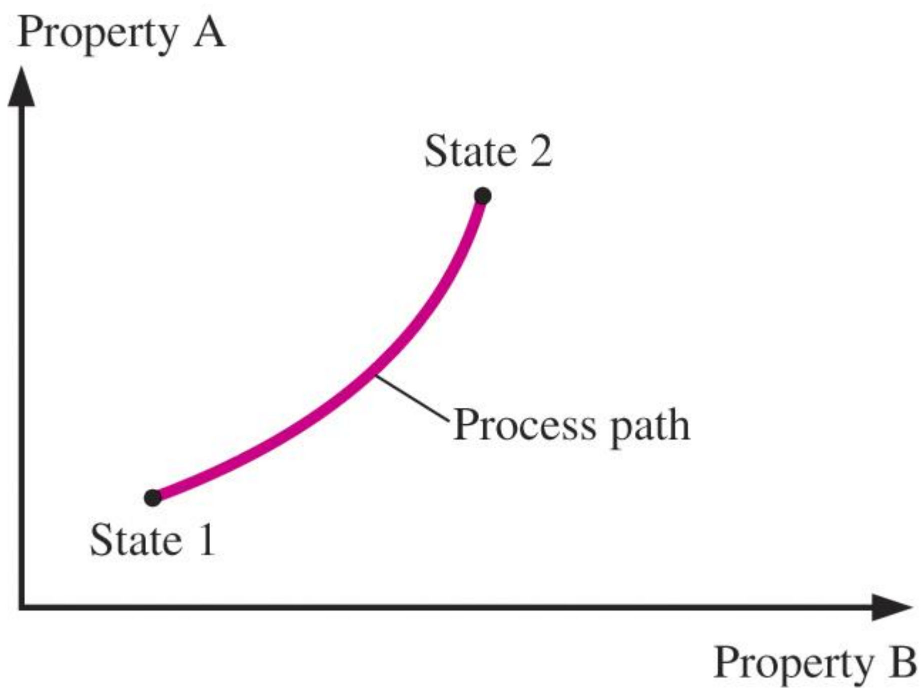
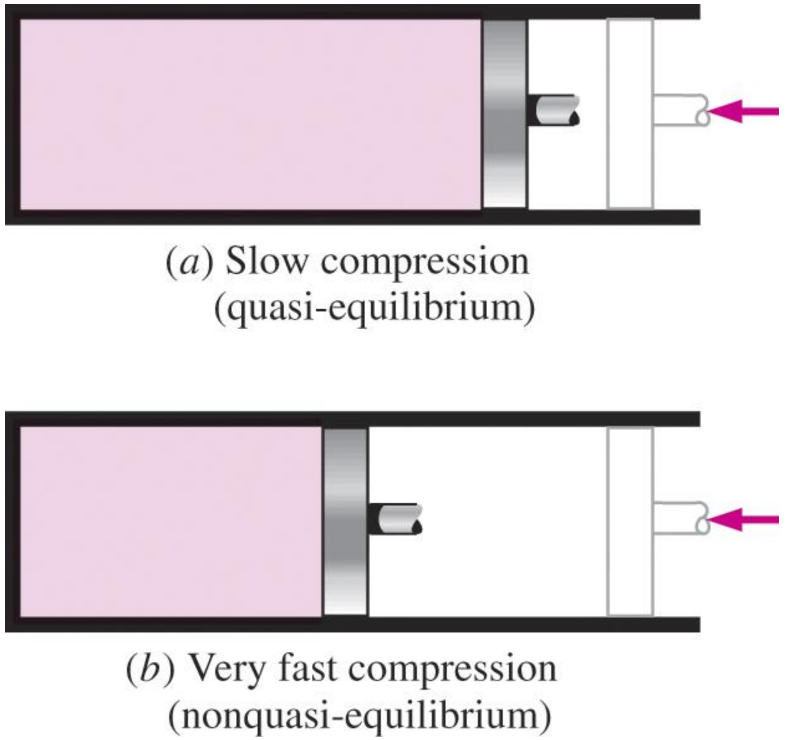
Process Diagrams





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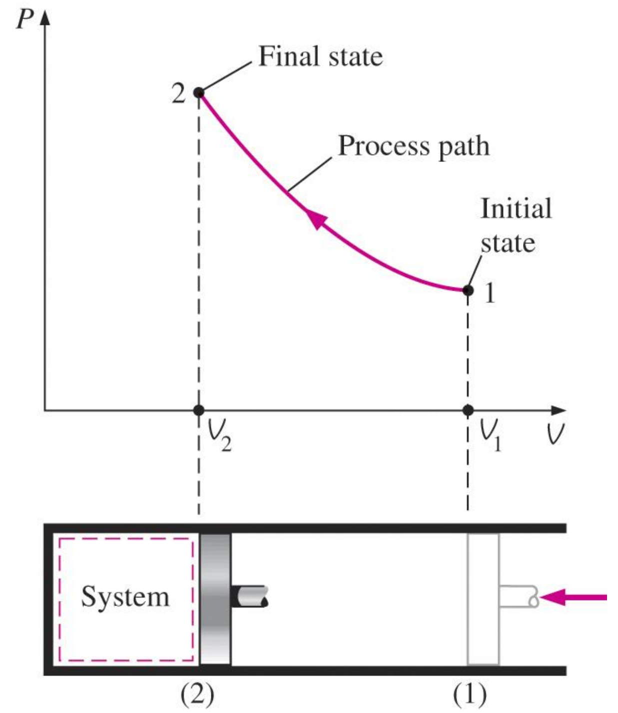
Process Diagrams

- Process diagrams are very useful in visualizing the processes.
- 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.



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

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Thermodynamic "Cycle"

- A sequence of processes which return the system to its initial state
  - Initial and final states are the same

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LECTURE # 3

Chapter 1 (Session #3):

Introduction and Basic Concepts

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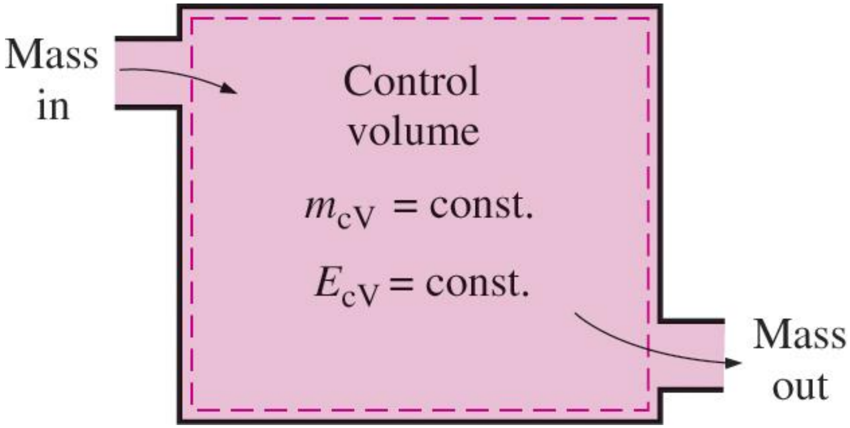
Steady Flow Process

- The term ***steady*** implies *no change with time*. The opposite of steady is *unsteady*, or *transient*.
- **Steady-flow process**: A process during which a fluid flows through a control volume steadily.



Under steady-flow conditions, the mass and energy contents of a control volume remain constant.

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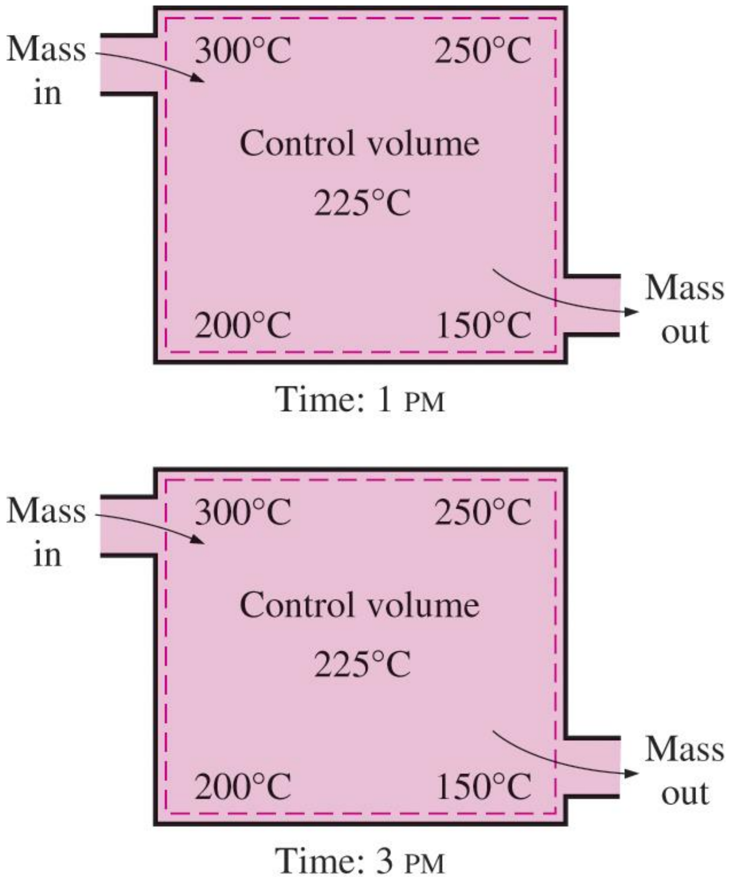
Steady Flow Process

- During a steady-flow process, fluid properties within the control volume may change with position but not with time.
- **Example:** Steady flow in a steam turbine – fluid enters the turbine at high P & T and exit at low P & T



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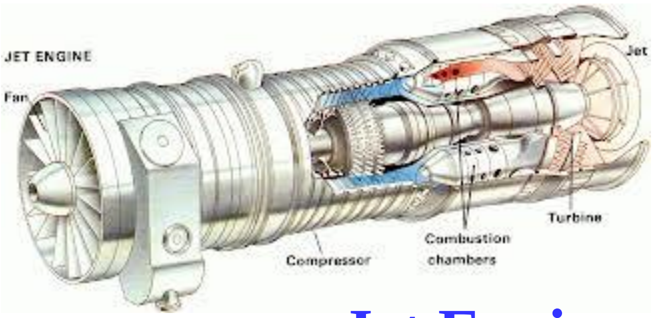
Steady Flow Devices

- Many engineering devices operate for long periods of time under the same conditions, and they are classified as *steady-flow devices*.
- **EXAMPLES:** turbines, pumps, boilers, condensers, and heat exchangers or power plants or refrigeration systems.



Jet Engine

Condenser

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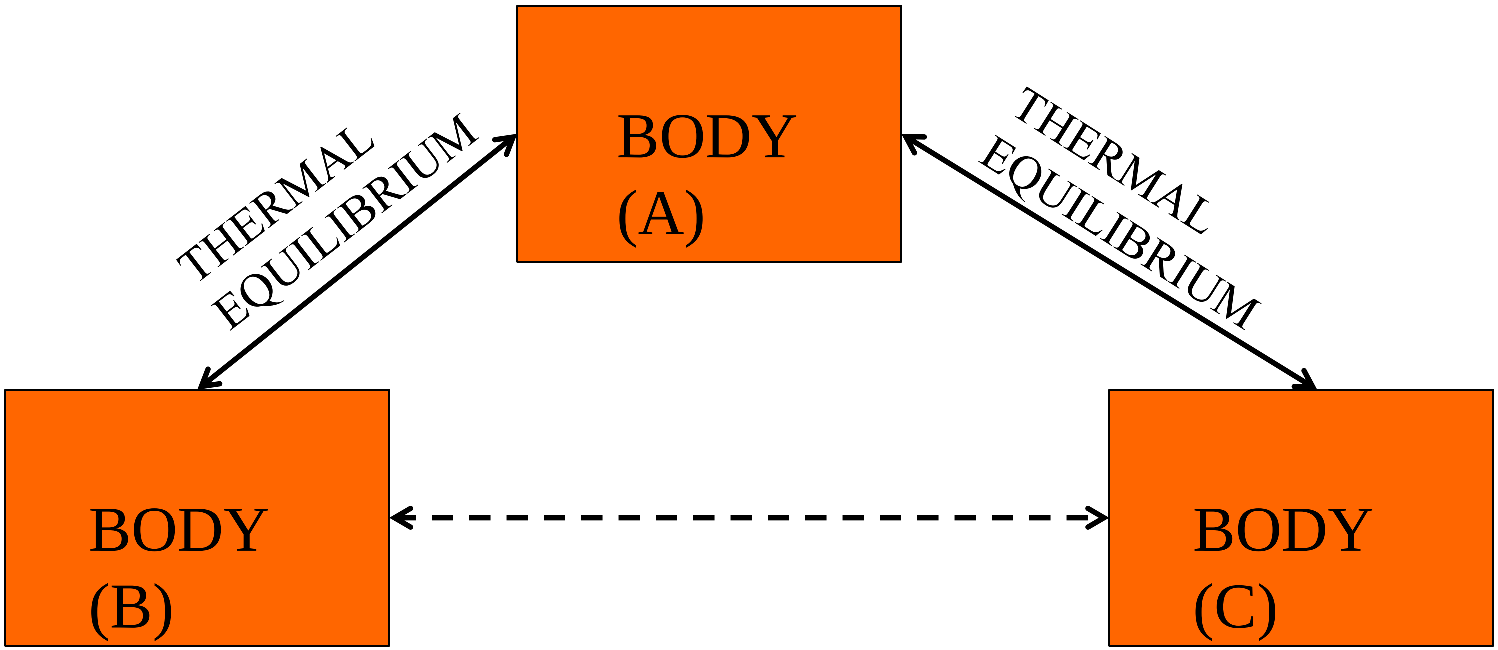
THE ZEROTH LAW OF THERMODYNAMICS

- **Two bodies, each in thermal equilibrium with a third body, are in thermal equilibrium with each other**



IMPLICATIONS OF THE ZEROTH LAW

- Temperature is a property -- fundamental dimension
- Zeroth Law offers basis for temperature measurement -- thermometer is the "third body"

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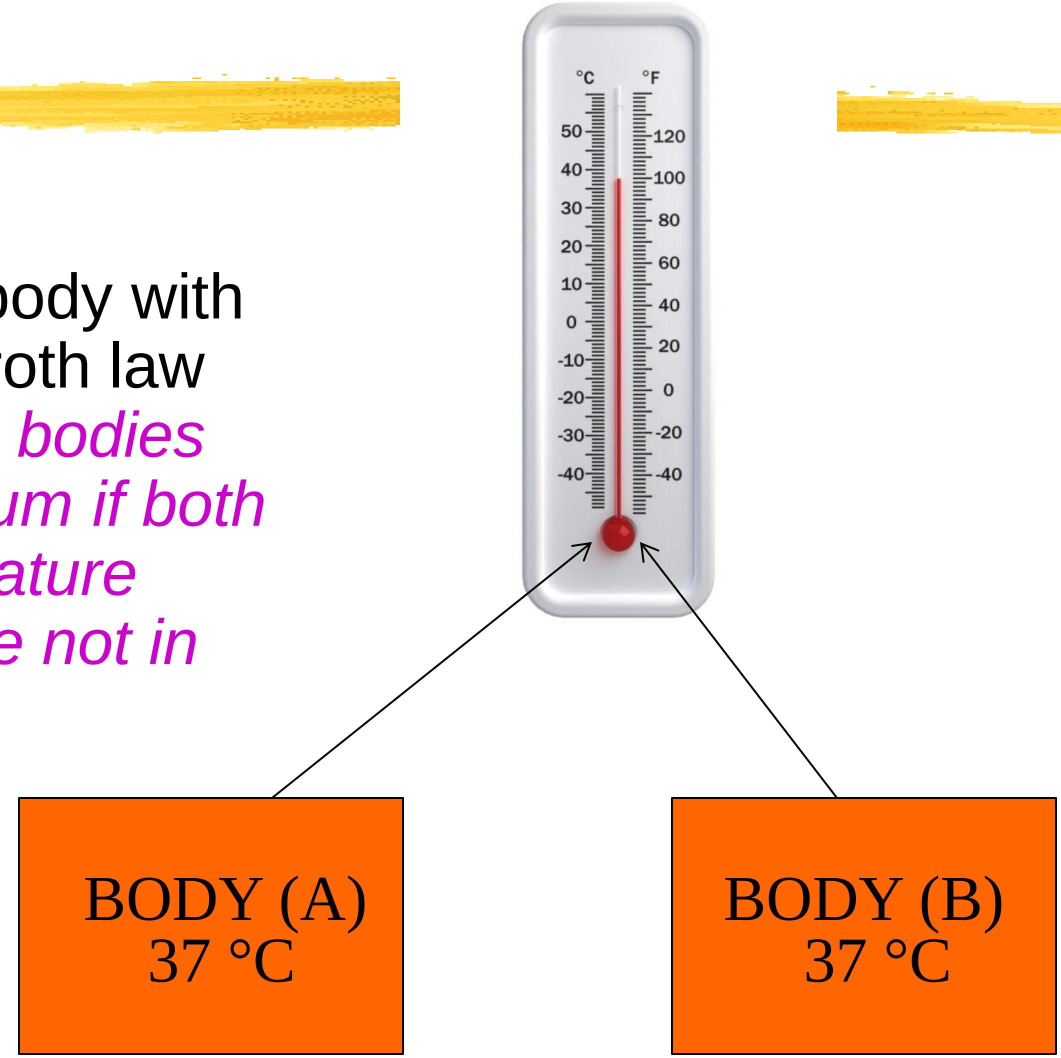
TEMPERATURE AND THE ZEROTH LAW OF THERMODYNAMICS

- 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

- A temperature scale is an "arbitrary" set of numbers and a method for assigning each number to a definite temperature
- 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.*
  - **Ice point**: A mixture of ice and water that is in equilibrium with air saturated with vapor at 1 atm pressure (0°C or 32°F).
  - **Steam point**: A mixture of liquid water and water vapor (with no air) in equilibrium at 1 atm pressure (100°C or 212°F).

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Temperature Scales

- **Celsius scale:**
  - Freezing point of water (@ 1 atm) = 0 °C
  - Boiling point of water (@ 1 atm) = 100 °C
- **Fahrenheit scale:**
  - Freezing point of water (@ 1 atm) = 32 °F
  - Boiling point of water (@ 1 atm) = 212 °F

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Thermodynamic Temperature Scale

- **Desirable to develop a temperature scale independent of the properties of any substance**
  - **A minimum temperature (an absolute zero) should be defined**
    - **There are no negative values**
    - **Lowest possible temperature in the universe**
- **Kelvin Scale (SI system of units)**
- **Rankine Scale (English system)**

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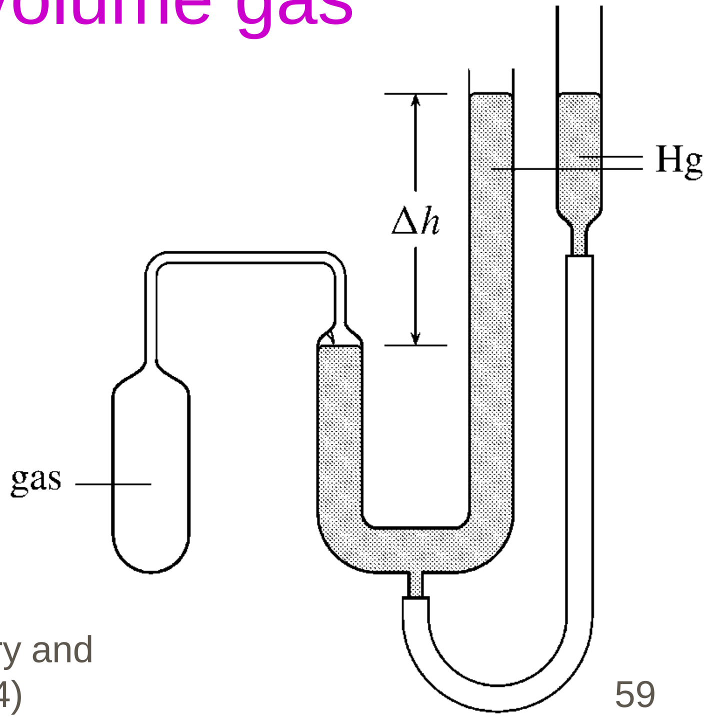
Ideal-Gas Temperature Scale

- A temperature scale nearly identical to the Kelvin scale is the **ideal-gas temperature scale**. The temperatures on this scale are measured using a constant-volume gas thermometer.



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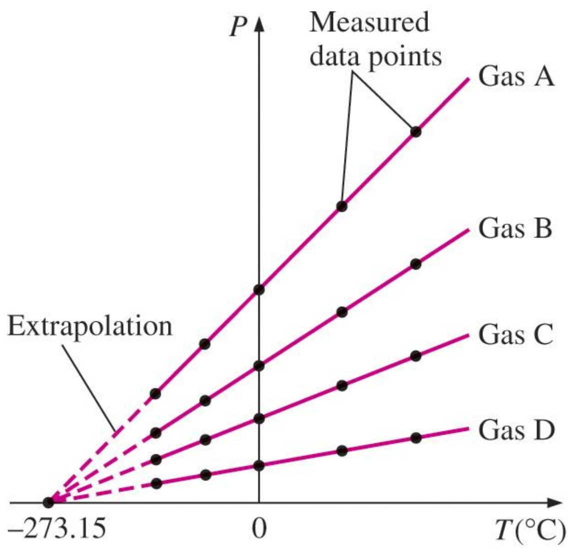
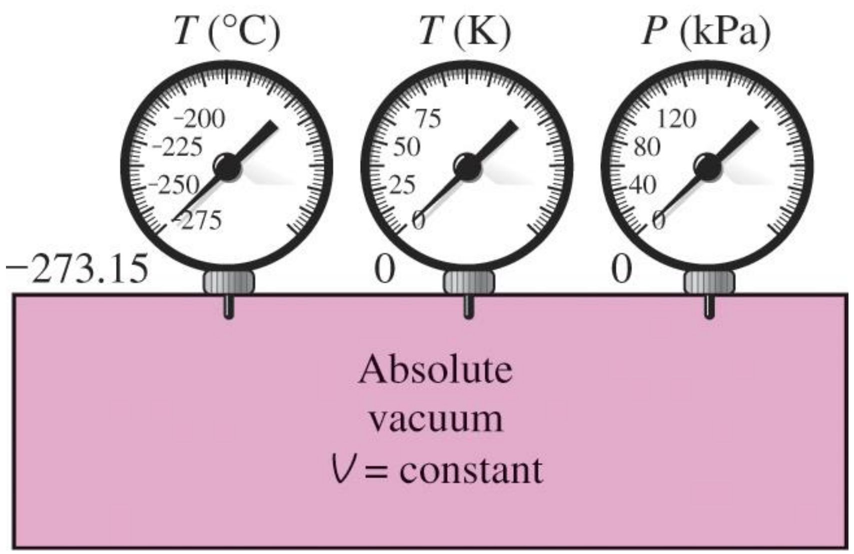
Ideal-Gas Temperature Scale





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.

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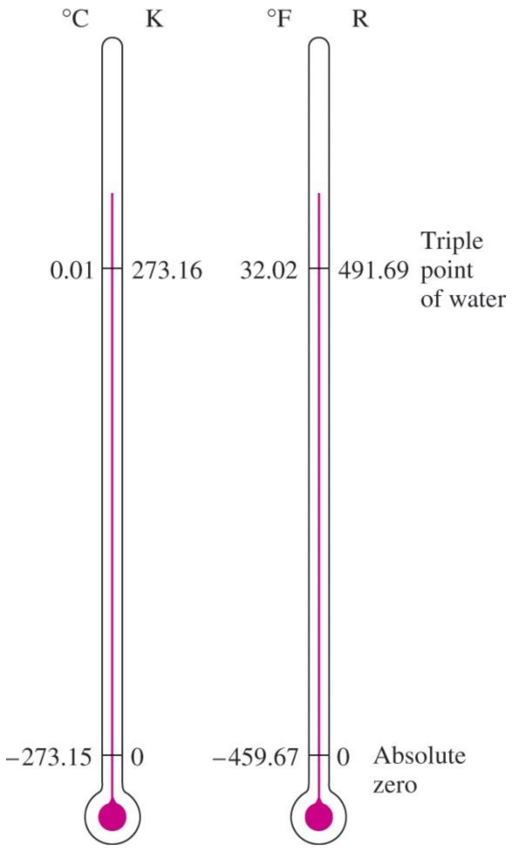
Thermodynamic Temperature Scale

- **Kelvin Scale (K)**
  - Absolute zero = 0 K
  - Triple point of water = 273.16 K
  - T (K) = T(°C) + 273.15
- **Rankine Scale (R)**
  - Absolute zero = 0 R
  - Triple point of water = 491.69 R
  - T (R) = T(°F) + 459.67



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Relation Between Temperature Scales

- $T(K) = T(^\circ C) + 273.15$
  - $\Delta T\ (K) = \Delta T\ (^\circ C)$
- $T(R) = T(^\circ F) + 459.67$
  - $\Delta T\ (R) = \Delta T\ (^\circ F)$
- $T(^\circ F) = 1.8\ T(^\circ C) + 32$
- $T(R) = 1.8\ T(K)$

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Pressure

- Force exerted by a **Fluid** per unit area normal to the force
  - In solids the normal stress is equivalent to pressure. Unlike solids, pressure in a fluid at a given point has same magnitude in all directions
- **Units:** Pressure = Force/Area = **N/m²**
  - 1 **Pascal** (Pa) = 1 N/m^2
  - 1 kPa = 10^3 Pa; 1MPa = 10^6 Pa
  - 1 bar = 100 kPa; 1 atm = 101.325 kPa

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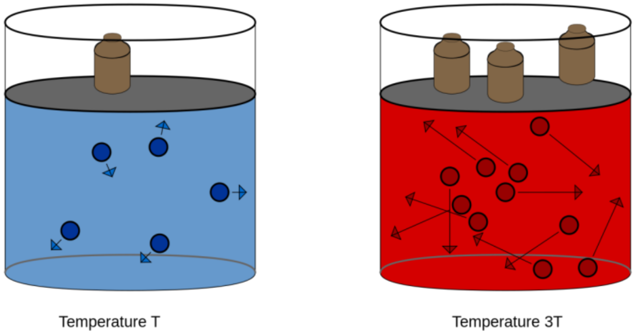
Pressure

- Pressure is sensed in gases by the forces exerted on system boundaries due to molecular collisions

- When molecules have higher kinetic energy (i.e. higher temperature), molecular collisions with system boundaries become stronger → pressure is higher
  - There is a proportional relationship between temperature and pressure in gases



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Absolute, Gage & Vacuum Pressure

- **Absolute Pressure, P_{abs}:**
  - Actual pressure at a point; measured relative to absolute vacuum (absolute zero pressure)
- **Gage Pressure, P_{gage}:**
  - Difference between absolute pressure and local atmospheric pressure ($P_{gage} = P_{abs} - P_{atm}$)
- **Vacuum Pressure, P_{vac}:**
  - Difference between atmospheric pressure and absolute pressure ($P_{vac} = P_{atm} - P_{abs}$)

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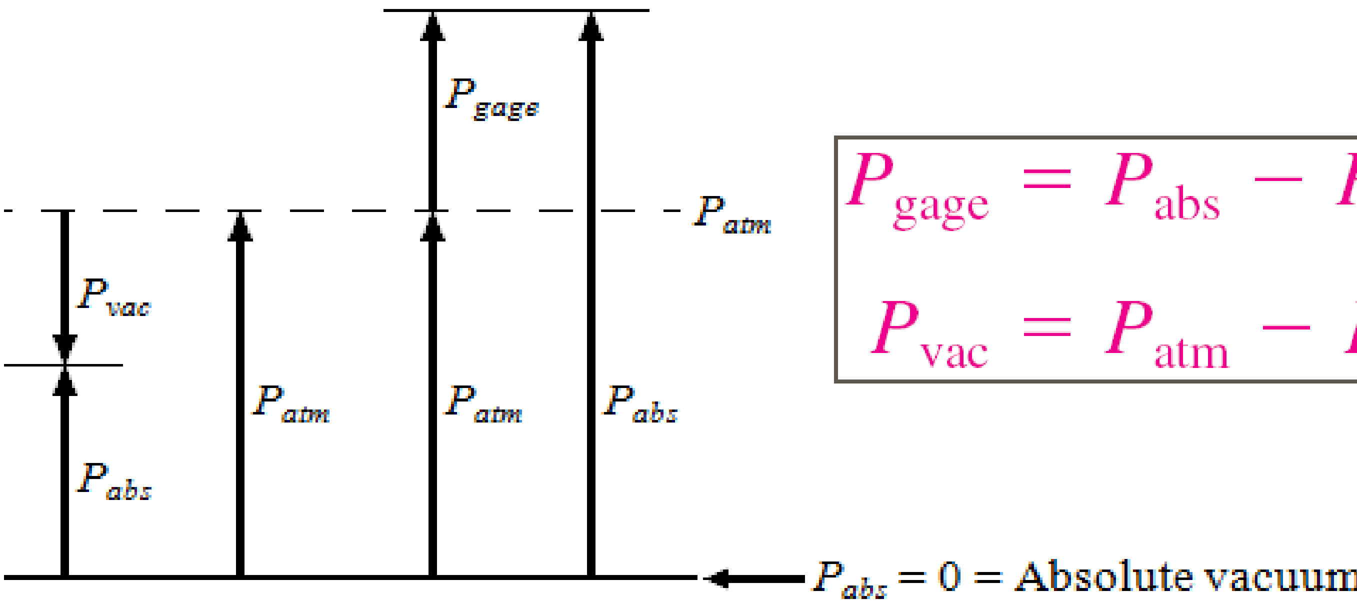
Absolute, Gage & Vacuum Pressure



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

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

Absolute and Gage Pressure

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

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