SKMM 2413 Thermodynamics

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Course outline

1. **Definitions & basic concepts** of thermodynamics
2. **Properties of Pure Substance** – Phase of Pure Substances, Phase Change Processes of Pure Substances. Property Diagram for Phase-Change Processes, Property Tables, Ideal Gas. Ideal Gas Equation of State. Property Diagram for Ideal Gases, Compressibility Factor, Other Equations of State (Van der Waals, Beattie-Bridgeman and Benedict-Webb-Rubin)
3. **Energy & Energy Transfer** – Kinetic, Potential & Internal Energy, Energy Transfer by Heat and Work, Electrical Work, Shaft Work, Spring Work, Boundary Work
4. **First law of thermodynamics (closed systems)**
5. **First law of thermodynamics (open systems)**
6. **Second law of thermodynamics**
7. **Entropy analysis**

Test 1 (20%)

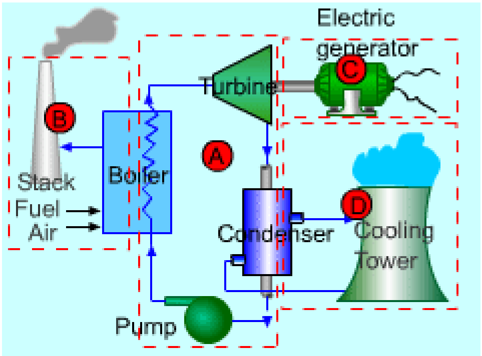
Test 2 (30%)

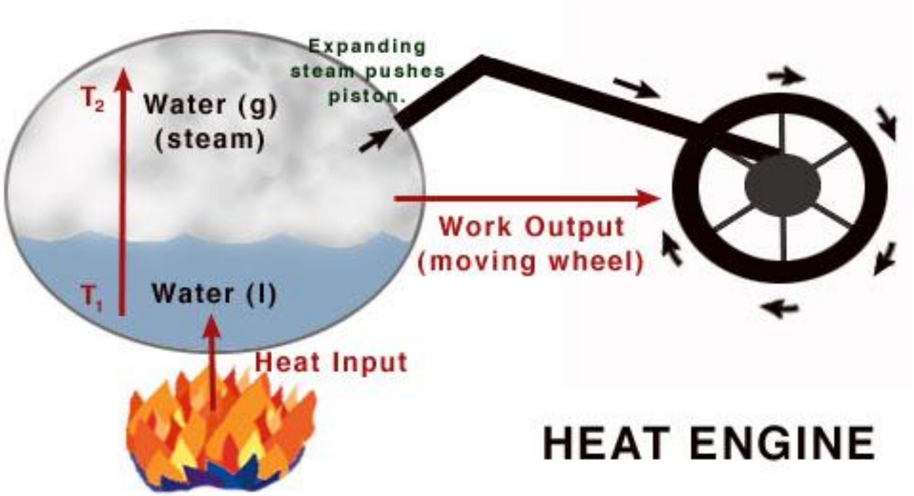
Final exam (40%)

Homework/quiz (10%):

Thermodynamics

- What is thermodynamics?
  - Thermodynamics is a branch of physical science that deals with heat and temperature and their relationship to energy and work (such as mechanical, electrical, nuclear or chemical energy).
- Importance to study thermodynamics
  - It is the major ingredient for modern technological advancement.





Application Areas of Thermodynamics

- Transport
- Power generation
- Industry
- Household
- Agriculture
- Comfort

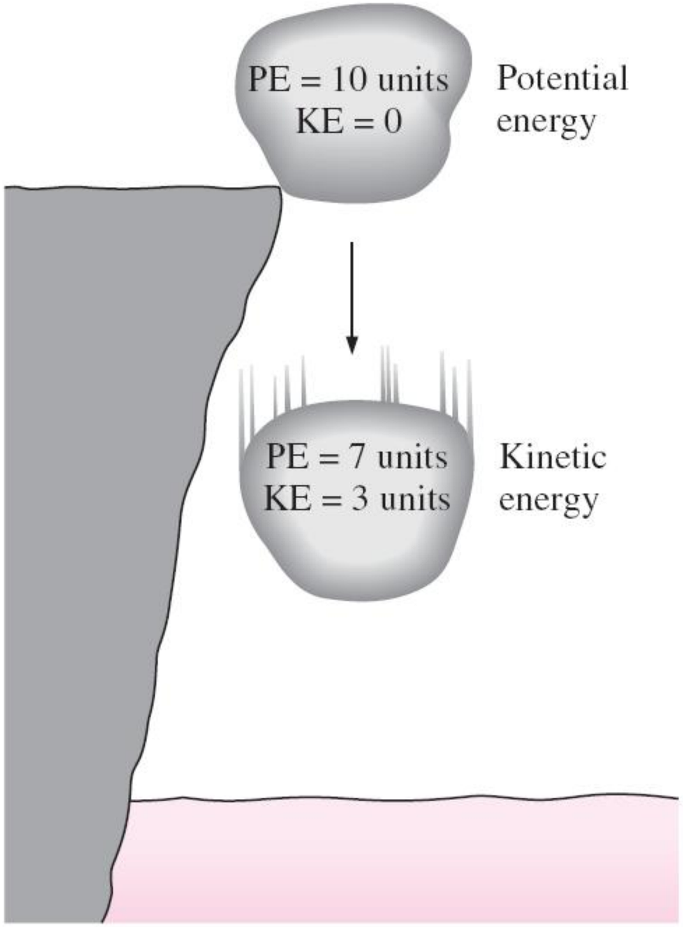
With the aid of GEA Grasso V1100 piston compressors and an automatic GEA Grasso control system, a Polish dairy co-operative increased its refrigeration capacity by 25% with the same power consumption

Importance of thermodynamics from multidisciplinary point of view

- Working in power generating plants
- Electrical and electronic industry-
  - Cooling system, compressor, solenoid
  - Thermal considerations in using semiconductors, use of heat sinks, use of forced air, detecting of air and fluid movement
  - Temperature measurement using NTC thermistors
- Renewable energy technology and industry
- Sustainability issues and environmental consideration
- Energy related trade and business

THERMODYNAMICS AND ENERGY

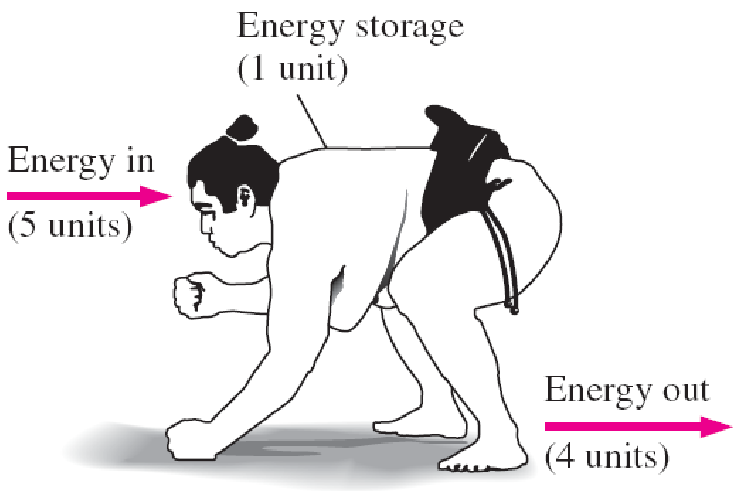
- The name *thermodynamics* stems from the Greek words *therme* (heat) and *dynamis* (power).
- **Energy** : Entity that able to cause changes (capacity to do changes)
- Thermodynamics are based on observation from the experimental studies
- **Heat** and **work** are two type of energy that relate to each other
- The relationship between heat and work is expressed using the Laws of Thermodynamics



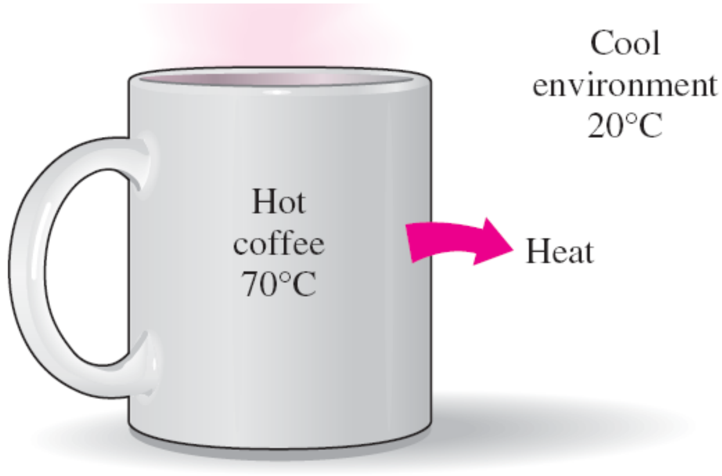
Energy cannot be created or destroyed; it can only change forms (the first law).

THERMODYNAMICS AND ENERGY

- **Laws of thermodynamics**
  - **Zeroth law:** If two systems are in thermal equilibrium with a third system, they must be in thermal equilibrium with each other
  - **First Law**: Energy cannot be created nor destroyed; it can only change forms
  - **Second law:** There is no cyclic process whose effect is to take heat from a reservoir and transform it completely into work (Lord Kelvin)
  - **Third law:**



Conservation of energy principle for the human body.



Heat flows in the direction of decreasing temperature.

- **Conservation of energy principle**: During an interaction, energy can change from one form to another but the total amount of energy remains constant.

- **There are two methods to study thermodynamics:**

a) **Classical thermodynamics**:

-A macroscopic approach

- concerned with the gross or average effect of many molecules

b) **Statistical thermodynamics**:

A microscopic approach

-considers behaviours of individual molecules

-involves a large number of equations to explain the behaviour of a system

System:

- A quantity of matter or a region in space chosen for study.
- We need a system just to focusing on the ‘matter or ‘region’ that we want to analyze.

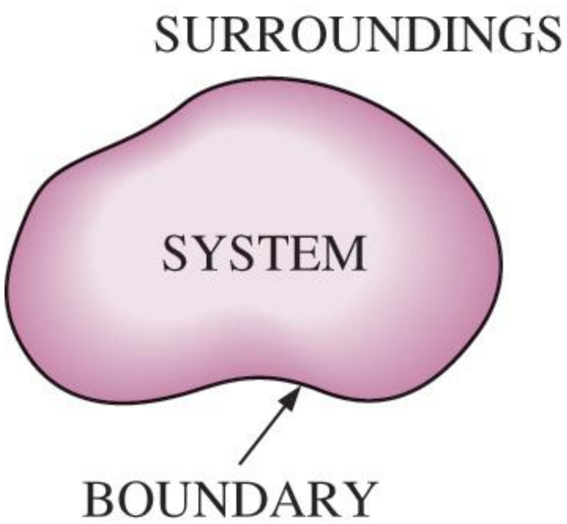
Surroundings:

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*
  - *Movable*

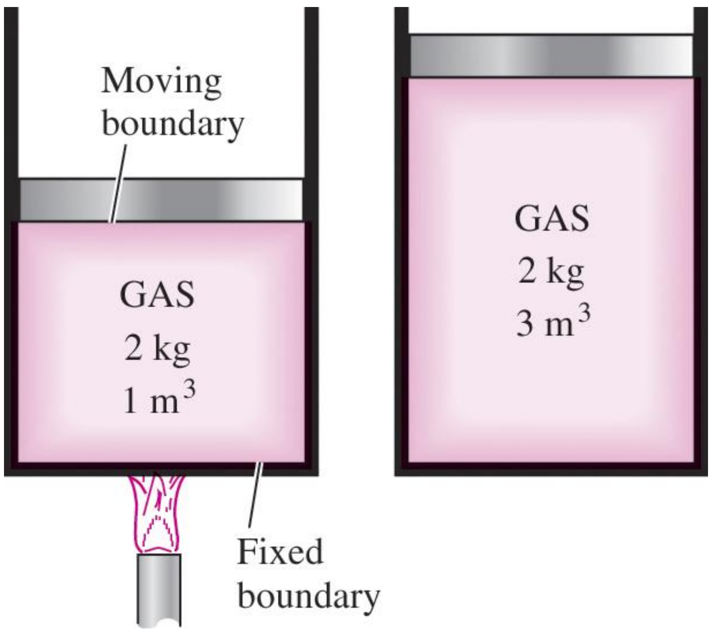


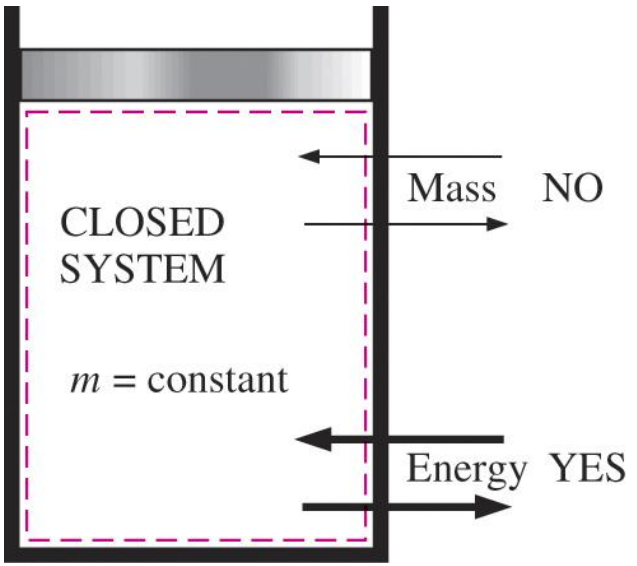
Systems can be three types:

- *Closed*
- *Open*
- *Isolated.*

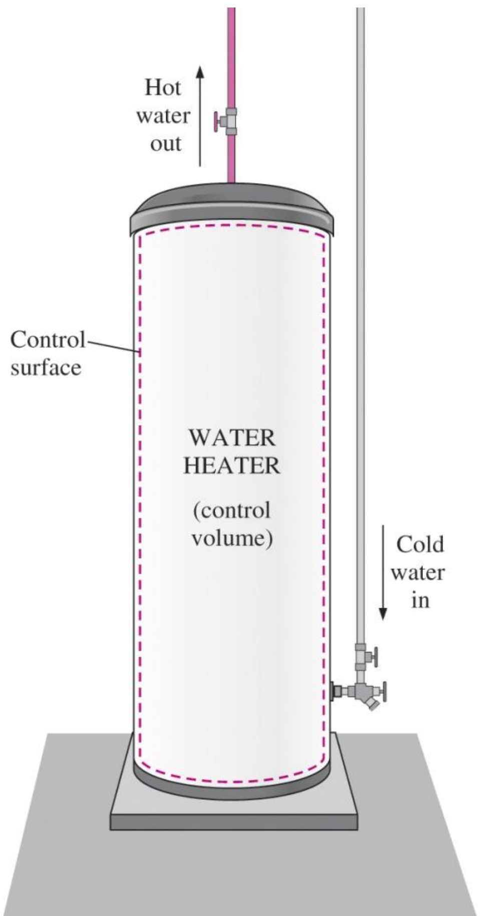
- **Closed system (or control mass):**
  - A fixed amount of mass, and no mass can cross its boundary.
  - Boundary can be fixed or moving of a closed system.
  - Energy or work can cross the boundary.

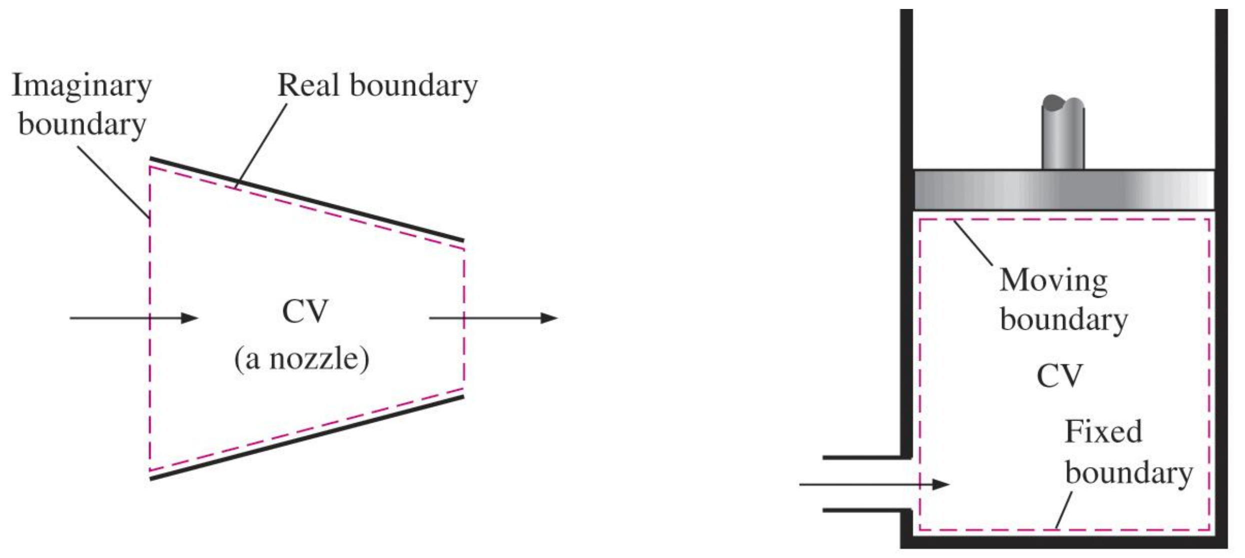
Example: Cylinder-piston assembly





- **Open system** (or **control volume)**: A properly selected region in space, fixed volume.
  - It usually encloses a device that involves mass flow
  - Both mass and energy/work can cross the boundary of a control volume.
- **Control surface**: The boundaries of a control volume. It can be real or imaginary.
- Examples: Compressor, turbine, nozzle, diffuser, expander etc.

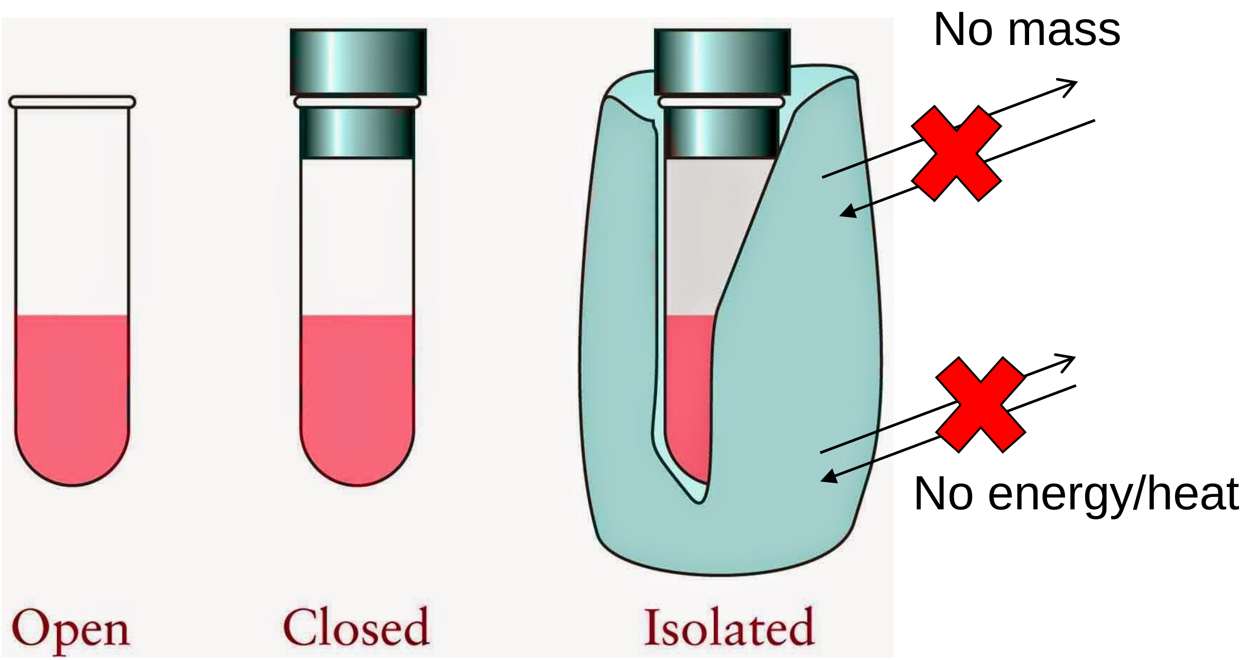




(*a*) A control volume with real and imaginary boundaries

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

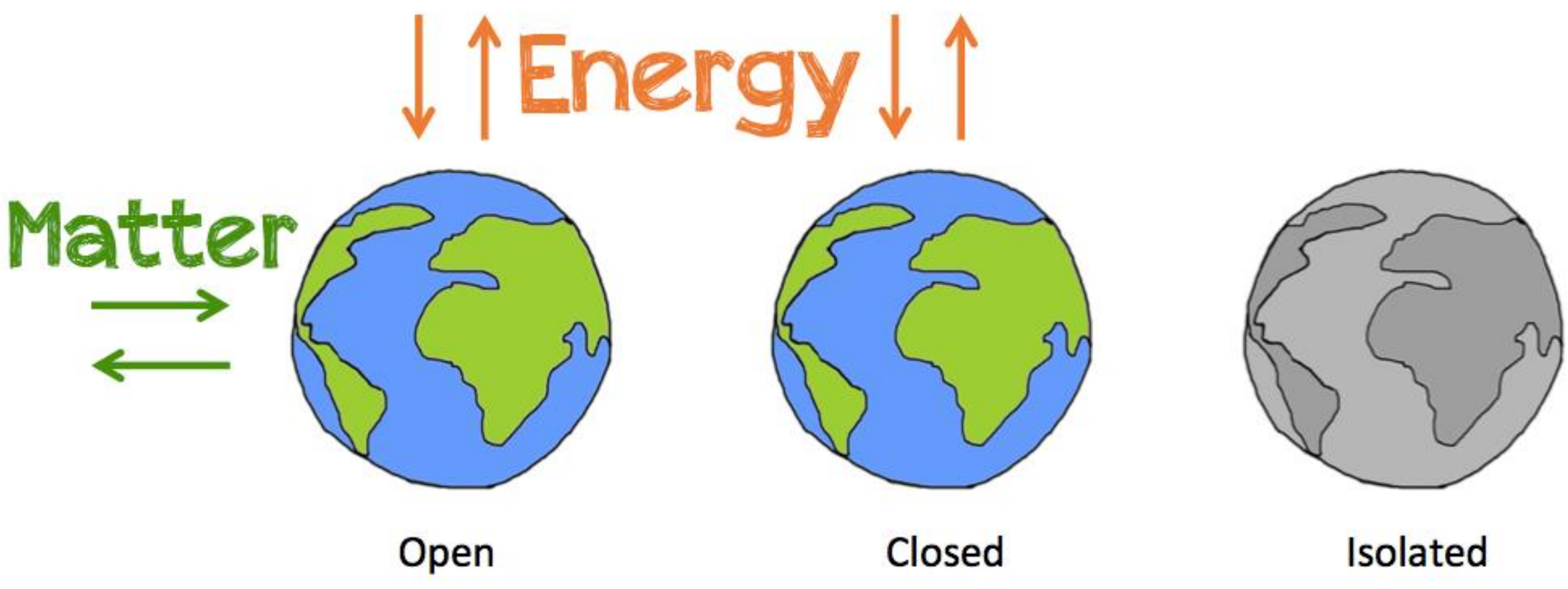
- Isolated system
  - Neither mass nor energy/work can cross the boundary of the system



Is our planet earth closed, open or isolated system?
(earth's boundary includes atmosphere)

✓ Either closed or open, never isolated.

(the Earth is an open system in longer geological timescales, e.g. matter exchange between the core and the mantle at the beginning of the earth. In shorter timescales, the Earth is nearly a closed system).



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*.

Name	Extensive	Intensive
Internal Energy	U (kJ)	u (kJ/kg)
Volume	V (m3)	v (m3/kg)
Enthalpy	H (kJ)	h (kJ/kg)
Temperature		T (K)
Pressure		P (Pa)
Density		ρ (kg/m3)

Criterion to differentiate intensive and extensive properties.

PROPERTIES

- **Intensive properties:** Those that are independent of the mass of a system, such as temperature, pressure, and density.
- Can't be added using algebra

- **Extensive properties:** Those whose values depend on the size—or extent—of the system.
- **Specific properties:** Extensive properties per unit mass.

DENSITY AND SPECIFIC GRAVITY

Density

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

Specific volume

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

Specific gravity: The ratio of the density of a substance to the density of some standard substance at a specified temperature (usually water at 4°C).

$$\mathrm{SG} = \frac{\rho}{\rho_{\mathrm{H_2O}}}$$

Specific weight: The weight of a unit volume of a substance.

$$\gamma_s = \rho g \qquad (\mathrm{N/m^3})$$

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

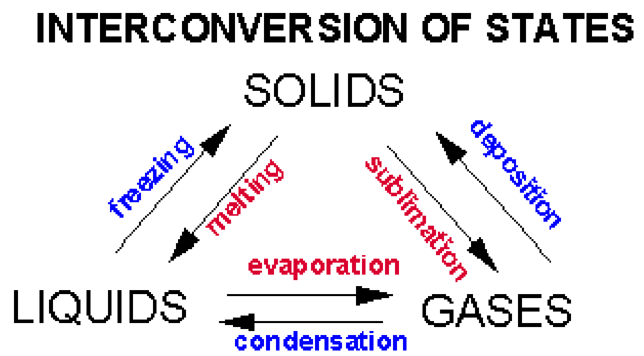
Density is mass per unit volume; specific volume is volume per unit mass.

TABLE 1–3

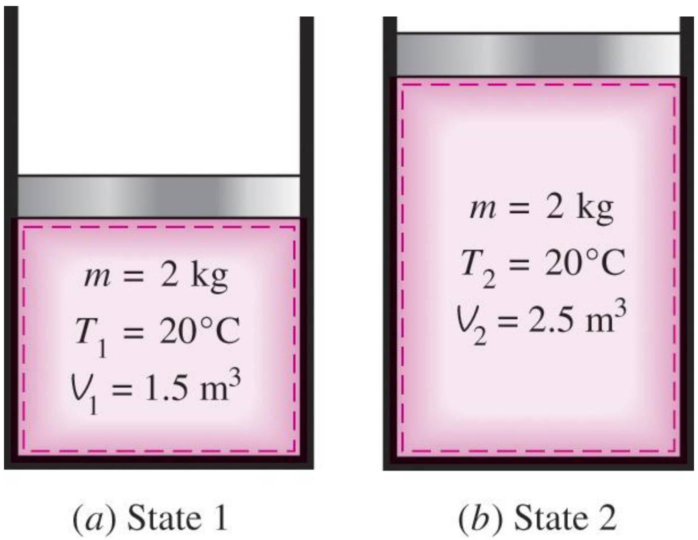
Specific gravities of some substances at 0°C

Substance	SG
Water	1.0
Blood	1.05
Seawater	1.025
Gasoline	0.7
Ethyl alcohol	0.79
Mercury	13.6
Wood	0.3–0.9
Gold	19.2
Bones	1.7–2.0
Ice	0.92
Air (at 1 atm)	0.0013

STATE AND EQUILIBRIUM



- **State**: When a system not undergoing any change, all its properties can be measured or calculated to completely describe its condition.
- The properties can only be defined when the system is in equilibrium state.
- **Equilibrium**: A state of balance.
- In an equilibrium state there are no unbalanced potentials (or driving forces) within the system.



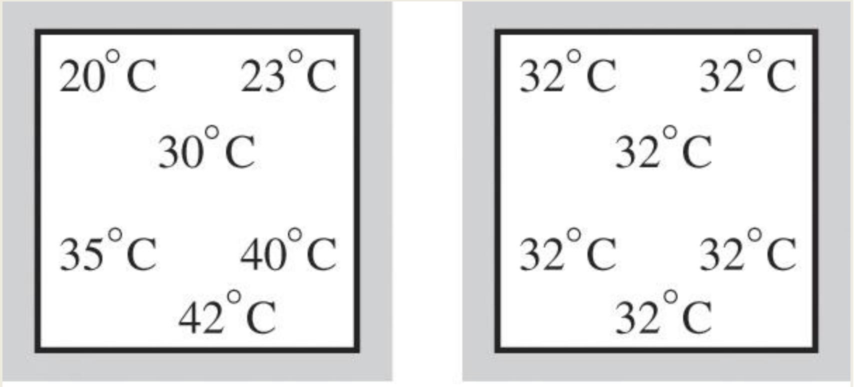
A system at two different states.

THERMODYNAMICS EQULIBRIUM

When no more pressure difference(dP=0), no temperature difference (dT=0) and no chemical reaction (dc=0) exist within the system.

EQUILIBRIUM

- **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.



(*a*) Before (*b*) After

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

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.

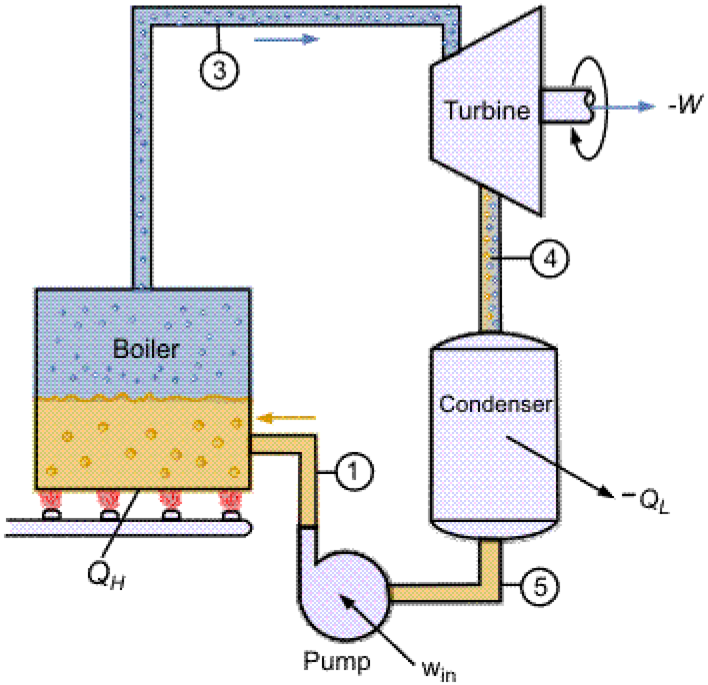
PROCESSES AND CYCLES

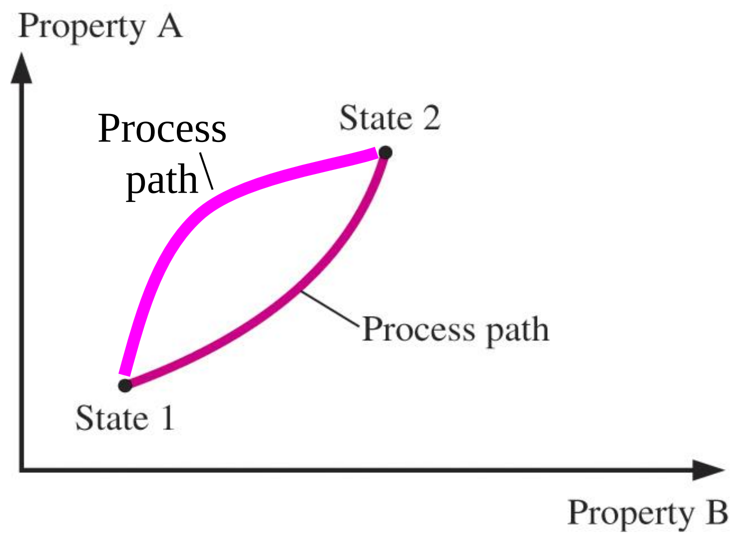
Process: Any **change** that a **system** undergoes from one **equilibrium state** to another.

Path: The series of states through which a system passes during a process.

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

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.

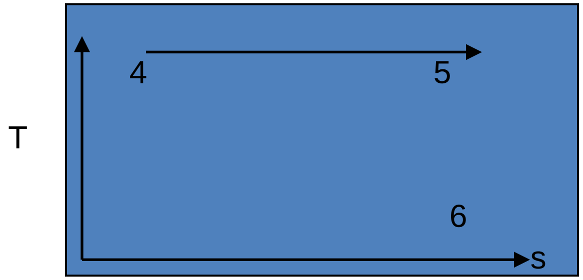




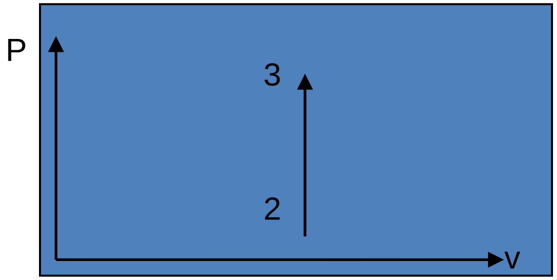
Process involved in thermodynamics:

- **Isobaric process**: A process during which the pressure *P* remains constant.(1→2 dP=0)

- **Isothermal process**: A process during which the temperature *T* remains constant.(4→5 dT=0)

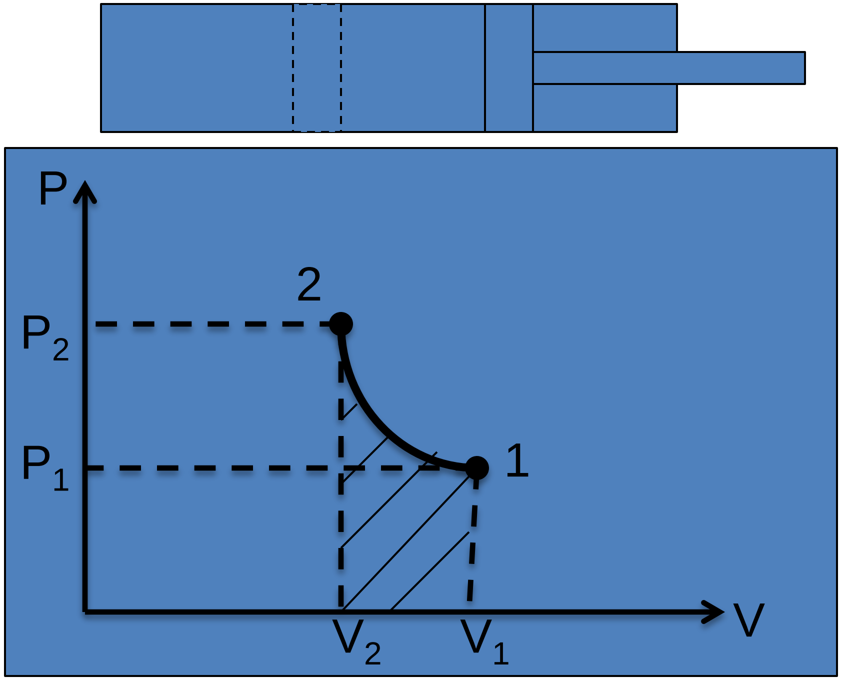


- **Isochoric (or isometric) process**: A process during which the specific volume *v* remains constant.(2→3 dv=0)



Process diagram

- Plotted by employing thermodynamics properties as coordinates (x axis, y axis)
- Common properties : Temperature, Volume, Pressure



The P-V diagram of a compression process

Revision

- A system is a quantity of matter or an region or space chosen for study (T/F)
- System boundary must be a real thing not virtual (T/F)
- System boundary may be fixed or moving (T/F)
- Closed system maintains fixed amount of mass (T/F).
- Open system has fixed volume (T/F)
- Density is an extensive property (Y/N)
- The situation of the system at which the properties completely describe the condition of the system is state (Y/N)
- A system undergoes a change from one state to another state . This system does a process (Y/N)
- The temperature all through the system is same in a thermally equilibrium system (T/F)

Another special process in thermodynamics

- **Adiabatic process**

  Process that not involving any heat transfer from the system to surrounding or from surroundings to the system.

  (Insulated system)

- **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.

- **Reversible process:**

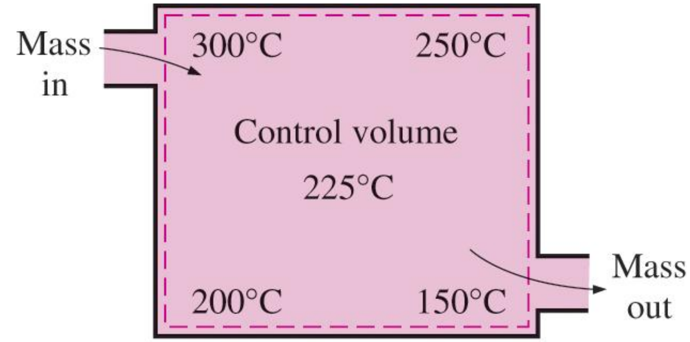
  Where the process from state 1 to state 2 and going back to state 1 again without loosing any properties change. ($W_{12}=W_{21}$)

Compressible work : $$W_{12} = \int_1^2 PdV$$

Expansion work: $$W_{21} = \int_2^1 PdV$$

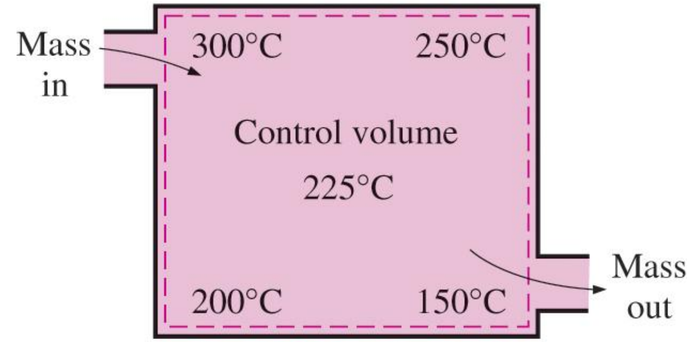
The Steady-Flow Process

- 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.



Time: 1 PM

During a steady-flow process, **fluid properties** within the control volume may **change with position** but **not with time**.



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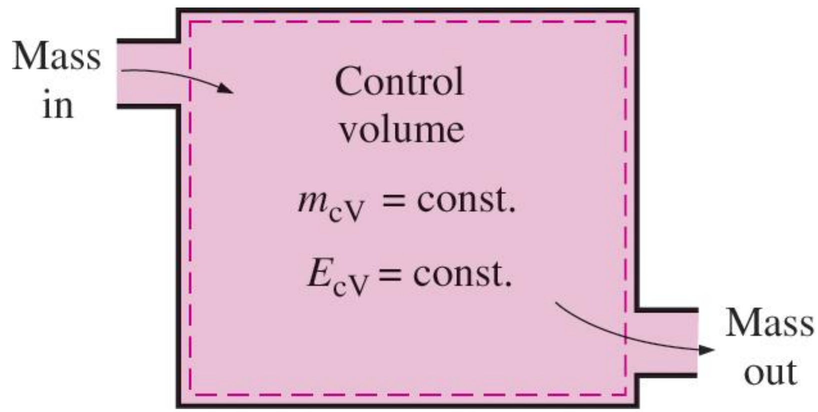
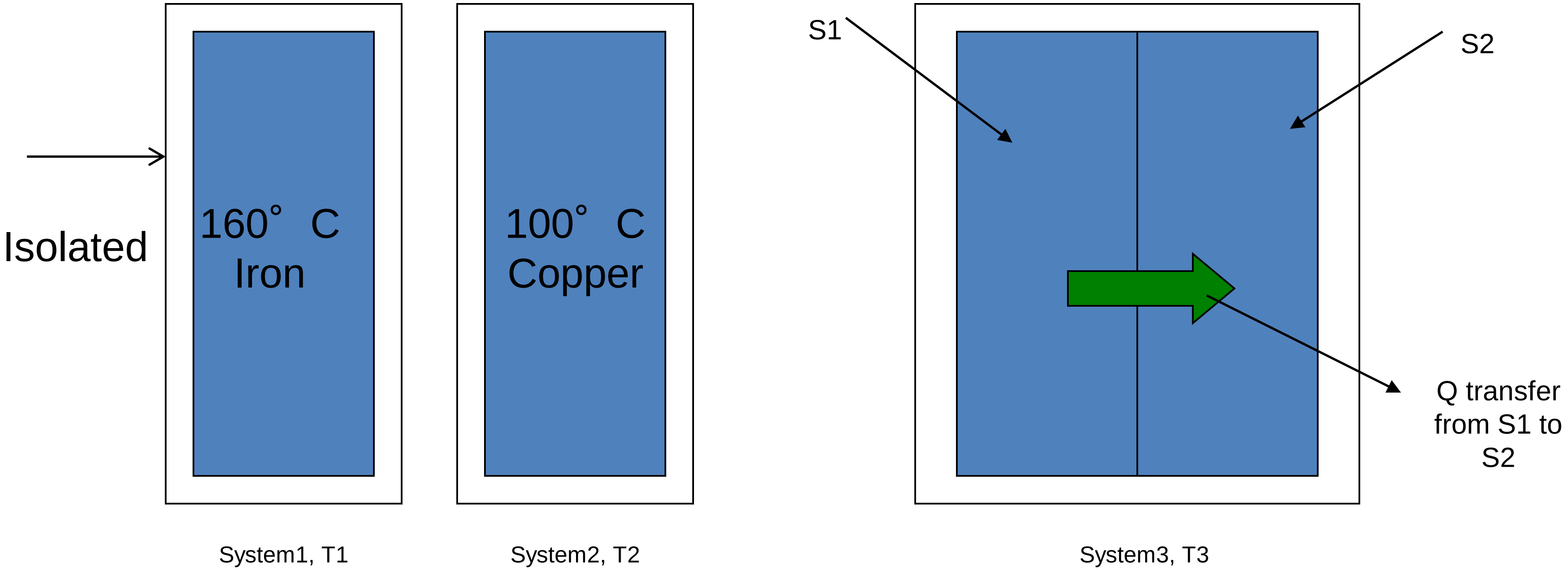


Under steady-flow conditions, the **mass** and **energy** contents of a control volume remain **constant**.

TEMPERATURE AND 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*.



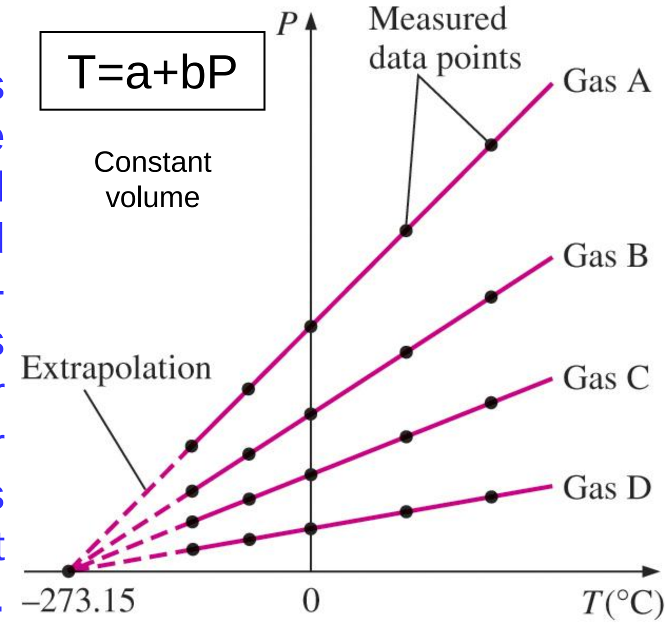
Temperature Scales

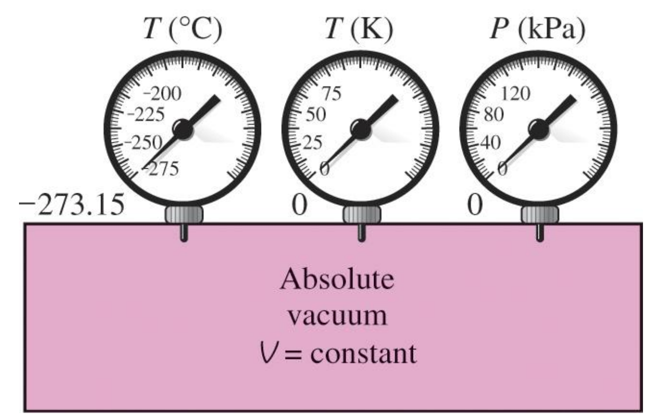
- Based on freezing and boiling points of water: the ***ice point*** and the ***steam point.***
- **Ice point**: 0°C or 32°F
- **Steam point**: 100°C or 212°F)
- **Celsius scale**: in SI unit system
- **Fahrenheit scale**: in English unit system
- **Thermodynamic temperature scale**: A temperature scale that is independent of the properties of any substance. (develop using 2^{nd} law of Thermodynamics)

  1. Kelvin scale (SI)

  2. Rankine scale (E)
- 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.

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.

Scientists theorized that the volume of a gas should become zero at a temperature of -273.15 C.

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

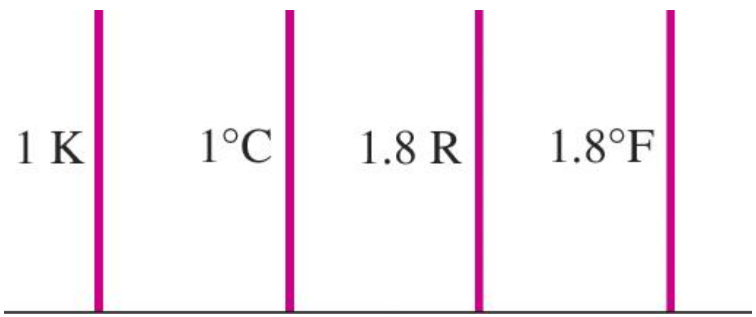
$$T(\mathrm{R}) = T(^\circ\mathrm{F}) + 459.67$$

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

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

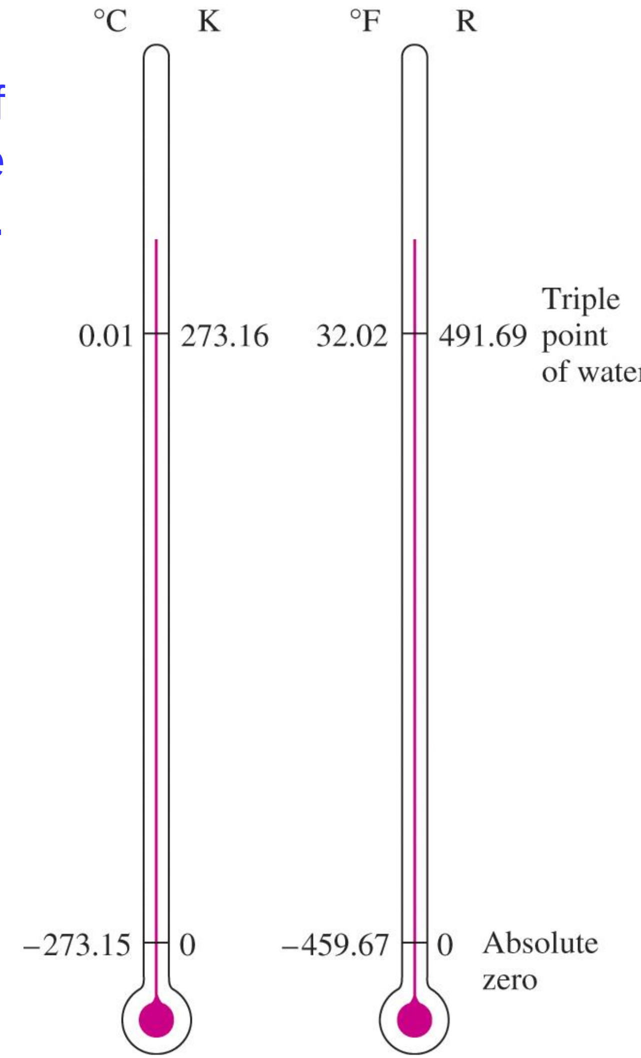
$$\Delta T(\mathrm{K}) = \Delta T(^\circ\mathrm{C})$$

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



Comparison of magnitudes of various temperature units.

Comparison of temperature scales.



Consider an alcohol and a mercury thermometer that read exactly 0°C at the ice point and 100°C at the steam point. The distance between the two points is divided into 100 equal parts in both thermometers. Do you think these thermometers will give exactly the same reading at a temperature of, say, 60°C? Explain.

PRESSURE

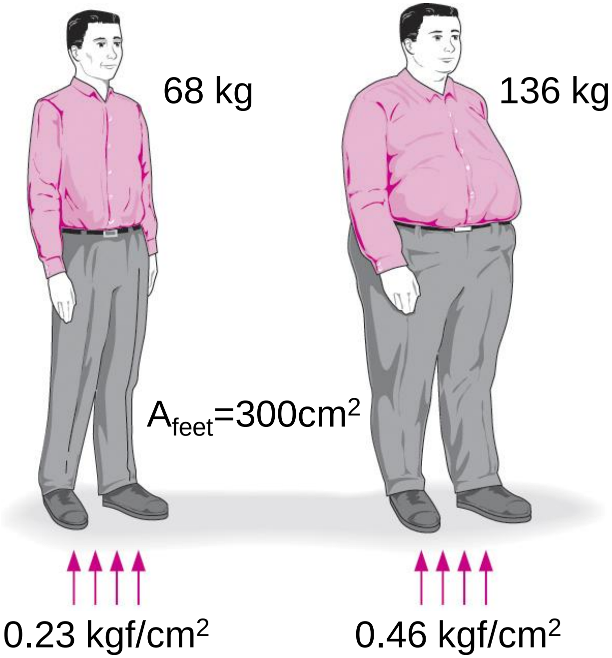
Pressure: A normal force exerted by a fluid per unit area

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

$$1 \text{ bar} = 10^5 \text{ Pa} = 0.1 \text{ MPa} = 100 \text{ kPa}$$

$$1 \text{ atm} = 101{,}325 \text{ Pa} = 101.325 \text{ kPa} = 1.01325 \text{ bars}$$

$$1 \text{ kgf/cm}^2 = 9.807 \text{ N/cm}^2 = 9.807 \times 10^4 \text{ N/m}^2 = 9.807 \times 10^4 \text{ Pa}$$
$$= 0.9807 \text{ bar}$$
$$= 0.9679 \text{ atm}$$



P=68/300=0.23 kgf/cm^2

The normal stress (or "pressure") on the feet of a chubby person is much greater than on the feet of a slim person.

Some basic pressure gages.

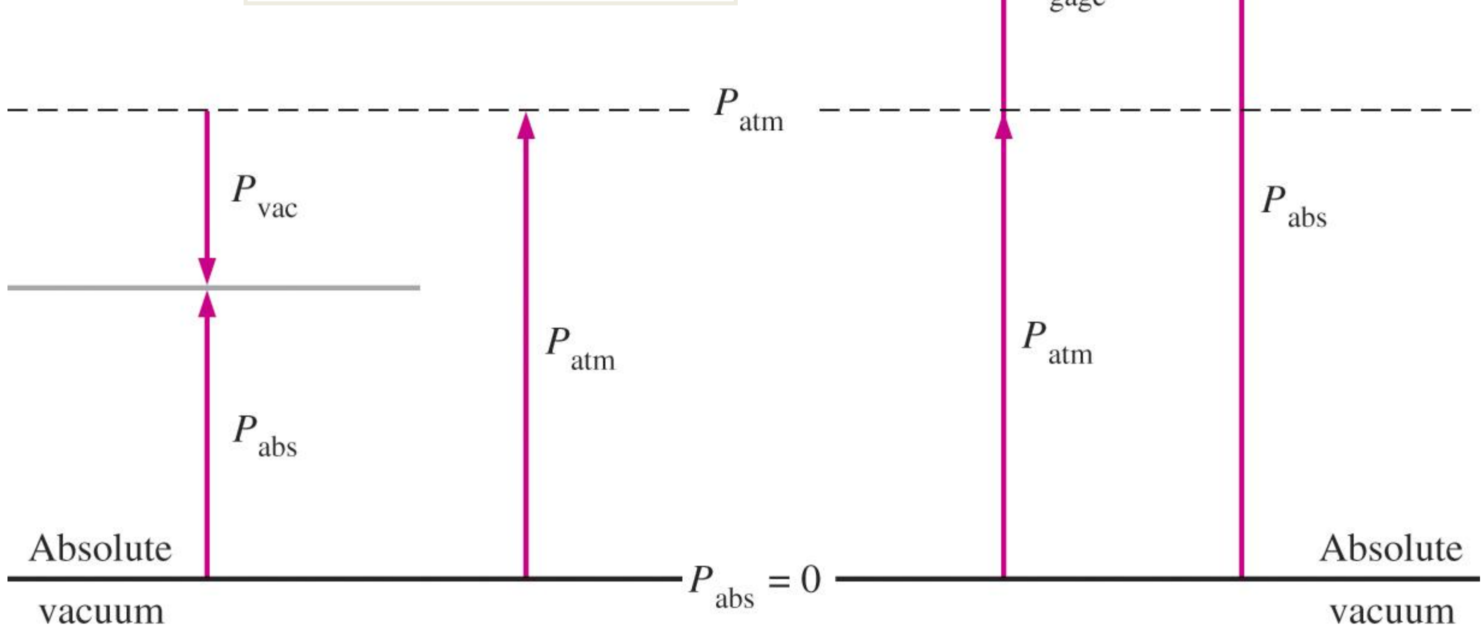
Fluid and liquid: pressure
Solid: normal stress

- **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.

Throughout this text, the pressure ***P*** will denote ***absolute pressure*** unless specified otherwise.

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

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



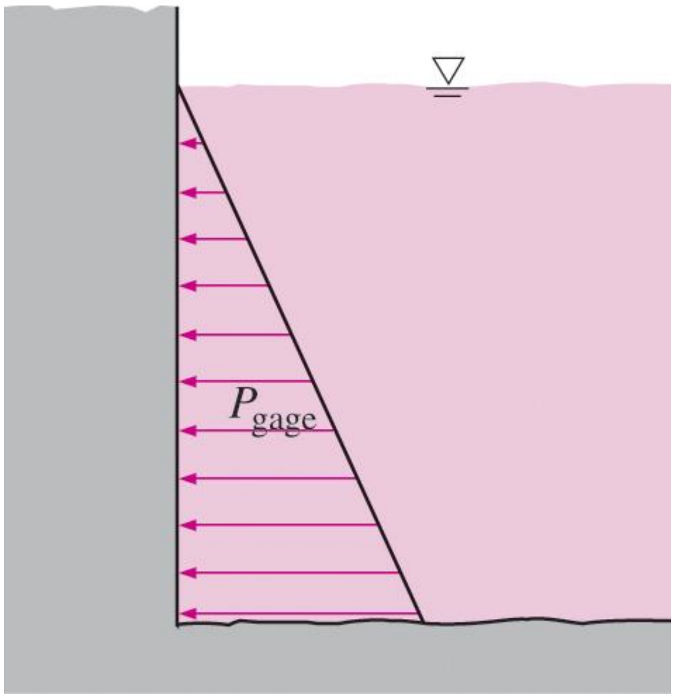
Variation of Pressure with Depth

$$\Delta P = P_2 - P_1 = \rho g \, \Delta z = \gamma_s \, \Delta z$$

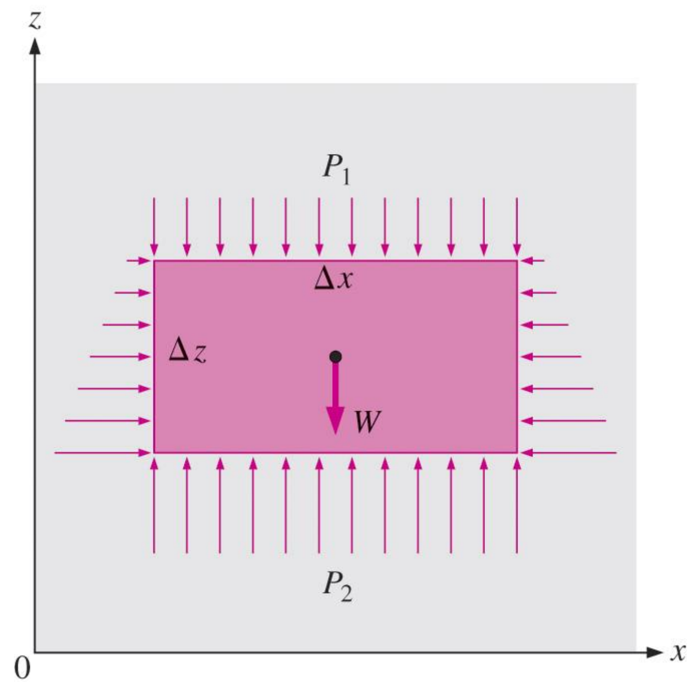
$$P = P_{atm} + \rho g h \quad \text{or} \quad P_{gage} = \rho g h$$

When the variation of density with elevation is known

$$\Delta P = P_2 - P_1 = -\int_1^2 \rho g \, dz$$



The pressure of a fluid at rest increases with depth (as a result of added weight).

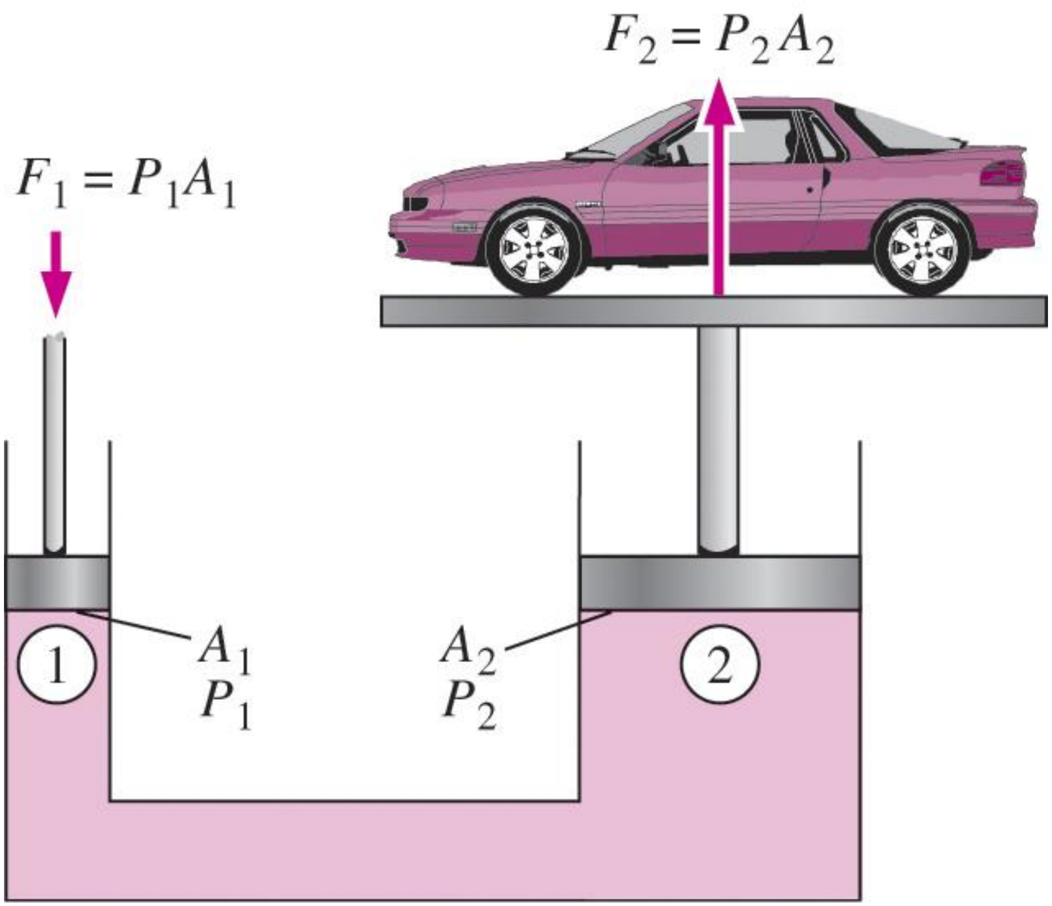


Free-body diagram of a rectangular fluid element in equilibrium.

Pascal's law: The pressure applied to a confined fluid increases the pressure throughout by the same amount.

$$P_1 = P_2 \quad \rightarrow \quad \frac{F_1}{A_1} = \frac{F_2}{A_2} \quad \rightarrow \quad \frac{F_2}{F_1} = \frac{A_2}{A_1}$$

The area ratio A_2/A_1 is called the *ideal mechanical advantage* of the hydraulic lift.



Lifting of a large weight by a small force by the application of Pascal's law.

Summary

- Thermodynamics and energy
  - Application areas of thermodynamics
- Importance of dimensions and units
  - Some SI and English units, Dimensional homogeneity, Unity conversion ratios
- Systems and control volumes
- Properties of a system
- Density and specific gravity
- State and equilibrium
  - The state postulate
- Processes and cycles
  - The steady-flow process
- Temperature and the zeroth law of thermodynamics
  - Temperature scales
- Pressure
  - Variation of pressure with depth
- Problem solving technique

1–15C A large fraction of the thermal energy generated in the engine of a car is rejected to the air by the radiator through the circulating water. Should the radiator be analyzed as a closed system or as an open system? Explain.

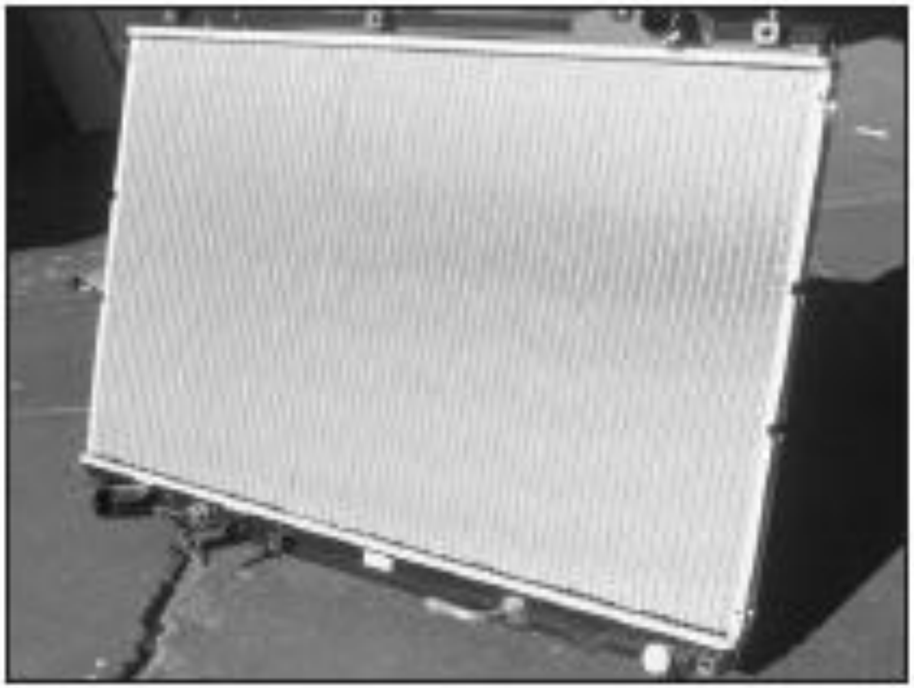


FIGURE P1–15C

1–16C A can of soft drink at room temperature is put into the refrigerator so that it will cool. Would you model the can of soft drink as a closed system or as an open system? Explain.

1–17C What is the difference between intensive and extensive properties?

1–18C For a system to be in thermodynamic equilibrium, do the temperature and the pressure have to be the same everywhere?

1–19C What is a quasi-equilibrium process? What is its importance in engineering?

1–20C Define the isothermal, isobaric, and isochoric processes.

1–21C What is the state postulate?

1–22C Is the state of the air in an isolated room completely specified by the temperature and the pressure? Explain.

1–23C What is a steady-flow process?

1–24C What is specific gravity? How is it related to density?

Temperature

1–26C What is the zeroth law of thermodynamics?

1–27C What are the ordinary and absolute temperature scales in the SI and the English system?

1–28C Consider an alcohol and a mercury thermometer that read exactly 0°C at the ice point and 100°C at the steam point. The distance between the two points is divided into 100 equal parts in both thermometers. Do you think these thermometers will give exactly the same reading at a temperature of, say, 60°C? Explain.

1–29 The deep body temperature of a healthy person is 37°C. What is it in kelvins?

1–31 The temperature of a system rises by 15°C during a heating process. Express this rise in temperature in kelvins.

Pressure, Manometer, and Barometer

1–34C What is the difference between gage pressure and absolute pressure?

1–35C Explain why some people experience nose bleeding and some others experience shortness of breath at high elevations.

1–36C Someone claims that the absolute pressure in a liquid of constant density doubles when the depth is doubled. Do you agree? Explain.

1–37C A tiny steel cube is suspended in water by a string. If the lengths of the sides of the cube are very small, how would you compare the magnitudes of the pressures on the top, bottom, and side surfaces of the cube?

1–38C Express Pascal's law, and give a real-world example of it.

1–39C Consider two identical fans, one at sea level and the other on top of a high mountain, running at identical speeds. How would you compare (*a*) the volume flow rates and (*b*) the mass flow rates of these two fans?

1–40 A vacuum gage connected to a chamber reads 35 kPa at a location where the atmospheric pressure is 92 kPa. Determine the absolute pressure in the chamber.

1–42 The water in a tank is pressurized by air, and the pressure is measured by a multifluid manometer as shown in Fig. P1–42. Determine the gage pressure of air in the tank if

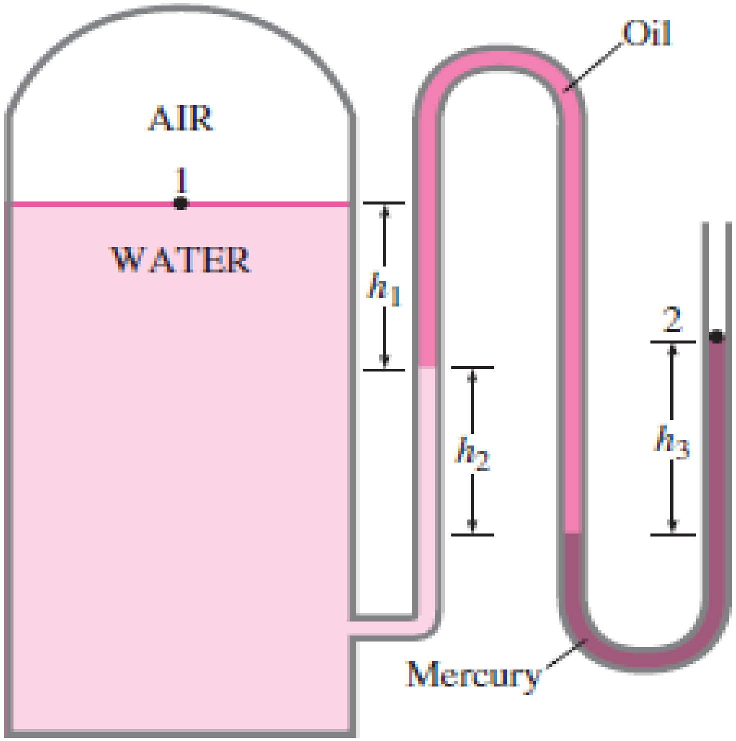


FIGURE P1–42

$h_1 = 0.2$ m, $h_2 = 0.3$ m, and $h_3 = 0.46$ m. Take the densities of water, oil, and mercury to be 1000 kg/m^3, 850 kg/m^3, and 13,600 kg/m^3, respectively.

1–57 A gas is contained in a vertical, frictionless piston–cylinder device. The piston has a mass of 4 kg and a cross-sectional area of 35 cm^2. A compressed spring above the piston exerts a force of 60 N on the piston. If the atmospheric pressure is 95 kPa, determine the pressure inside the cylinder. *Answer: 123.4 kPa*

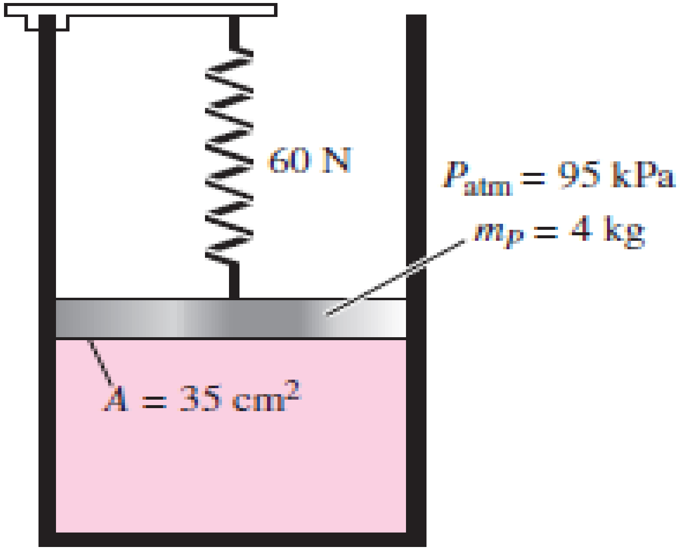


FIGURE P1–57