Thermodynamics: An Engineering Approach, 5th Edition
Yunus A. Cengel, Michael A. Boles
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Chapter 1
INTRODUCTION AND BASIC CONCEPTS

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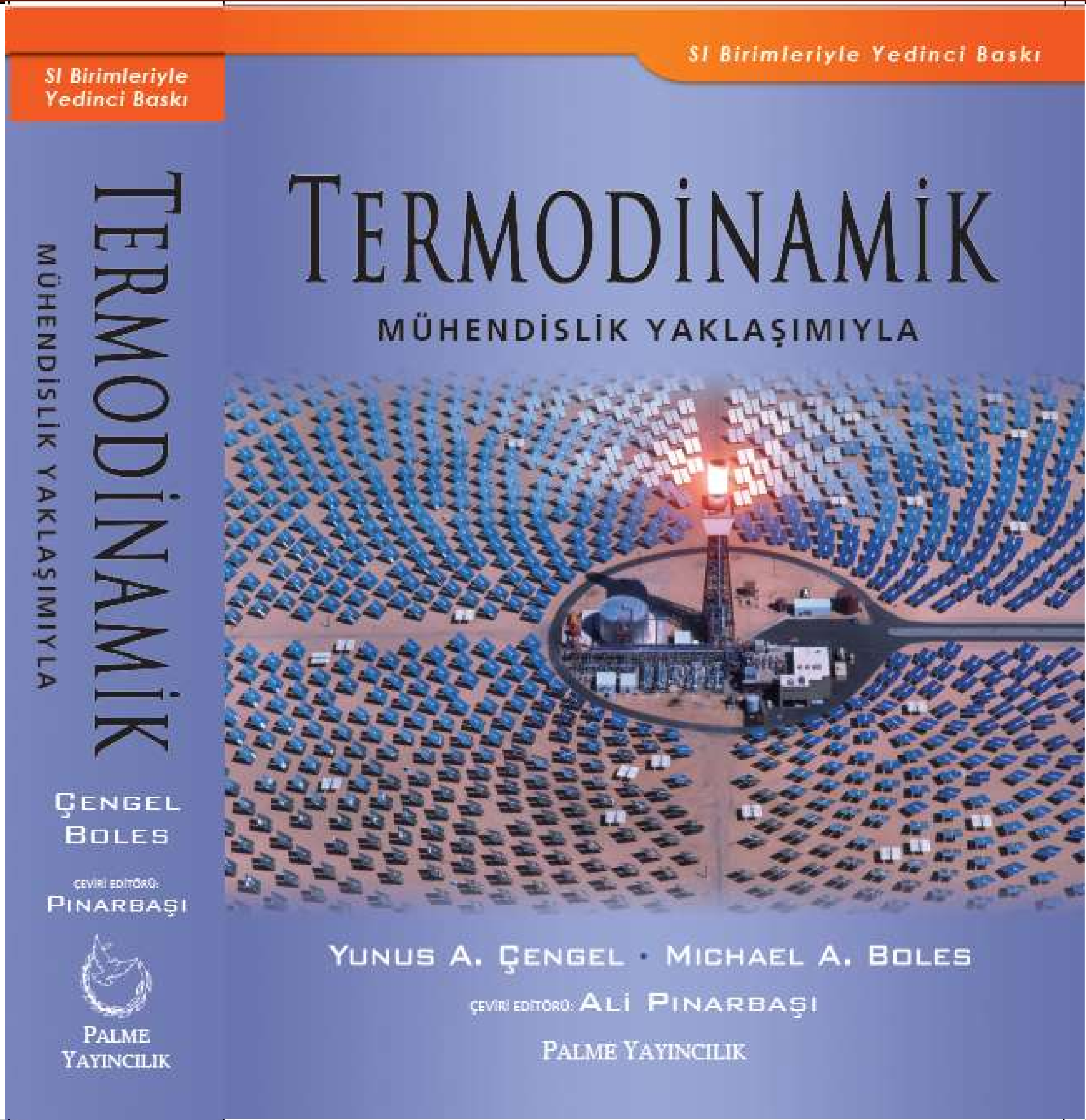
SI Birimleriyle Yedinci Baskı
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TERMODİNAMİK
MÜHENDİSLİK YAKLAŞIMIYLA
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ÇENGEL
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ÇEVİRİ EDİTÖRÜ:
PINARBAŞI
PALME
YAYINCILIK
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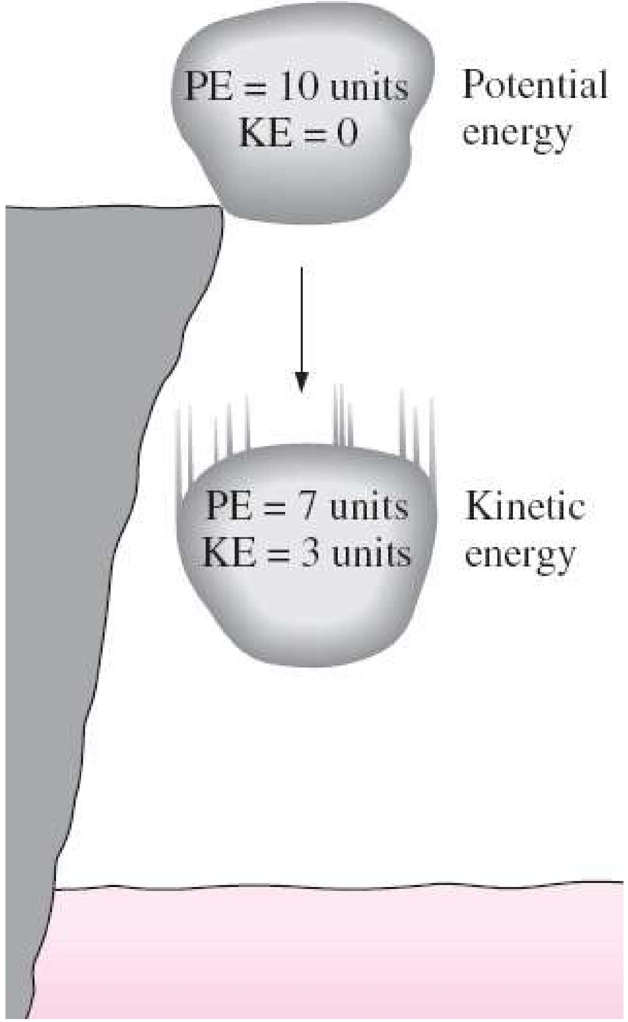
ÇEVİRİ EDİTÖRÜ: ALİ PINARBAŞI
PALME YAYINCILIK

Objectives

- Identify the unique vocabulary associated with thermodynamics through the precise definition of basic concepts to form a sound foundation for the development of the principles of thermodynamics.
- Review the metric SI and the English unit systems.
- Explain the basic concepts of thermodynamics such as system, state, state postulate, equilibrium, process, and cycle.
- Review concepts of temperature, temperature scales, pressure, and absolute and gage pressure.
- Introduce an intuitive systematic problem-solving technique.

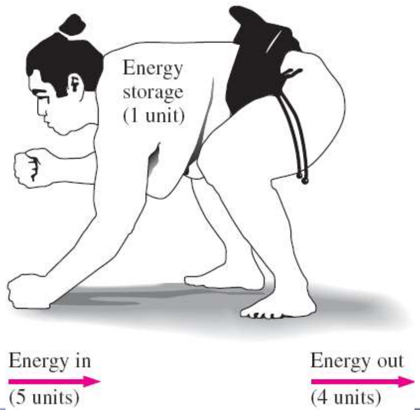
THERMODYNAMICS AND ENERGY

- **Thermodynamics**: The science of *energy*.
- **Energy**: The ability to cause changes.
- The name *thermodynamics* stems from the Greek words *therme* (heat) and *dynamis* (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.

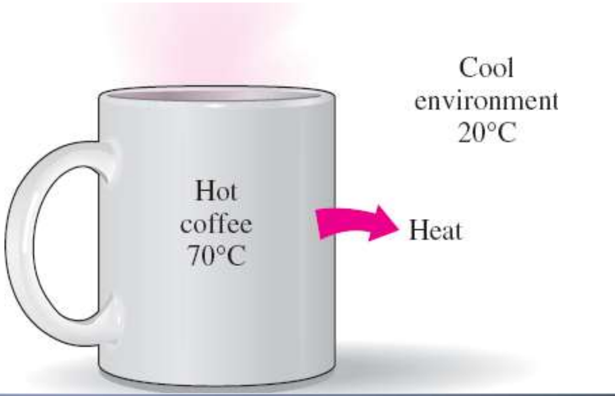


Energy cannot be created or destroyed; it can only change forms (the first law).

- **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.
- It is used in this text only in the supporting role.

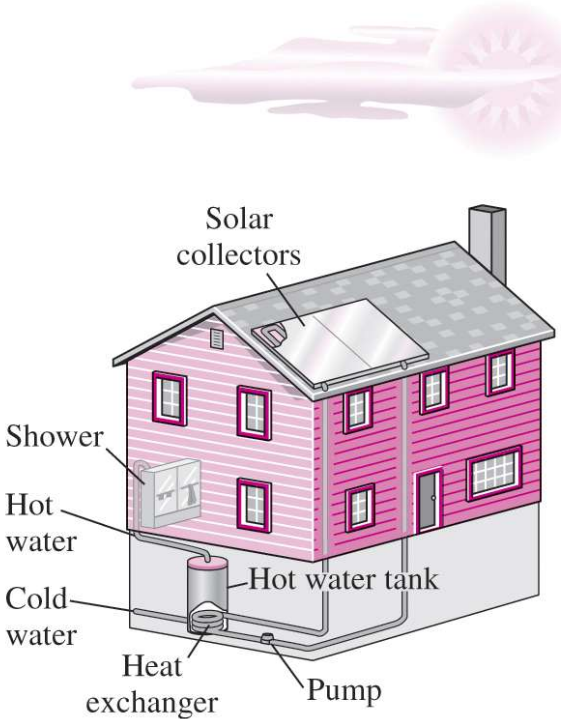


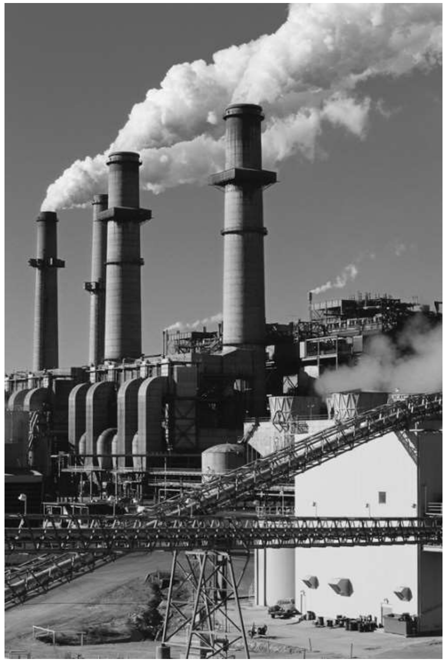
Conservation of energy principle for the human body.



Heat flows in the direction of decreasing temperature.

APPLİCATİON AREAS OF THERMODYNAMİCS





IMPORTANCE OF DIMENSIONS AND UNITS

- Any physical quantity can be characterized by **dimensions**.
- The magnitudes assigned to the dimensions are called **units**.
- Some basic dimensions such as mass *m*, length *L*, time *t*, and temperature *T* are selected as **primary** or **fundamental dimensions**, while 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**.
- **Metric SI system**: A simple and logical system based on a decimal relationship between the various units.
- **English system**: It has no apparent systematic numerical base, and various units in this system are related to each other rather arbitrarily.

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)

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

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

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

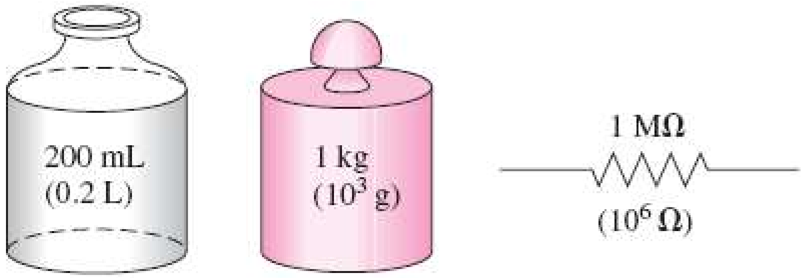
$$\text{Work} = \text{Force} \times \text{Distance}$$
$$1 \text{ J} = 1 \text{ N·m}$$
$$1 \text{ cal} = 4.1868 \text{ J}$$
$$1 \text{ Btu} = 1.0551 \text{ kJ}$$

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

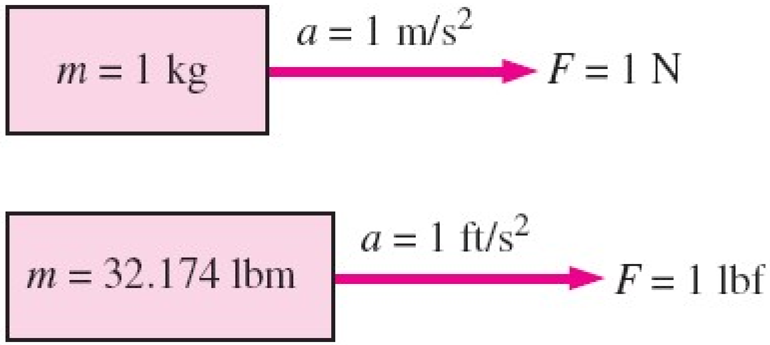
$$F = ma$$

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

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



The SI unit prefixes are used in all branches of engineering.

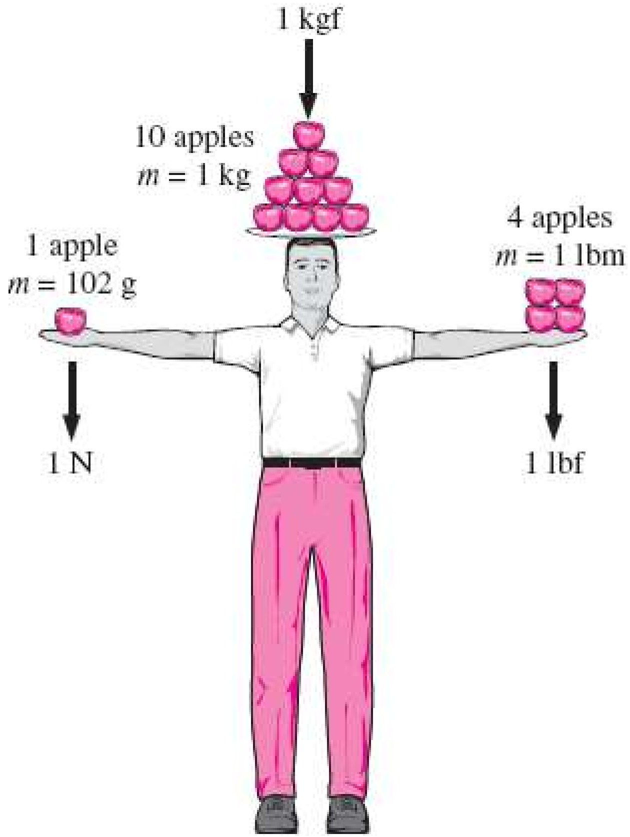


The definition of the force units.

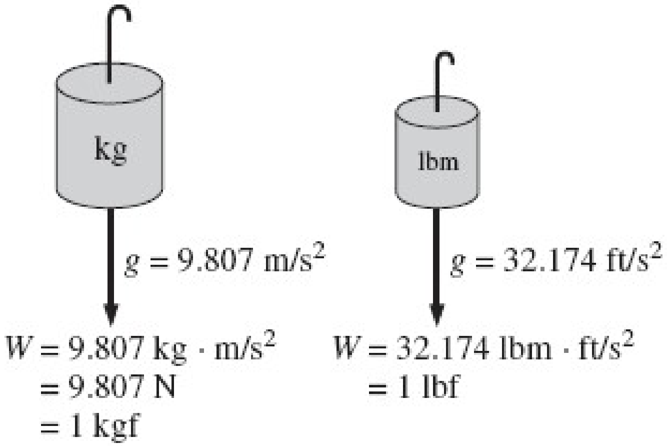
A body weighing 60 kgf on earth will weigh only 10 kgf on the moon.

$$W = mg \qquad \text{(N)}$$

W weight
m mass
g gravitational acceleration



The relative magnitudes of the force units newton (N), kilogram-force (kgf), and pound-force (lbf).



The weight of a unit mass at sea level.

Dimensional homogeneity

All equations must be dimensionally **homogeneous**.

UNITY CONVERSION RATIOS

All nonprimary units (secondary units) can be formed by combinations of primary units.
Force units, for example, can be expressed as

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

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

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

Unity conversion ratios are identically equal to 1 and are unitless, and thus such ratios (or their inverses) can be inserted conveniently into any calculation to properly convert units.

To be dimensionally homogeneous, all the terms in an equation must have the same unit.

EXAMPLE 1–1

While solving a problem, a person ended up with the following equation at some stage:
***E*= 25 kJ ± 7 kJ/kg** where *E* is the total energy and has the unit of kilojoules. Determine the error that may have caused it.

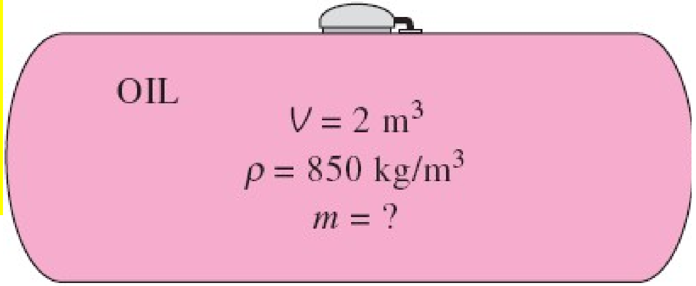
Solution During an analysis, a relation with inconsistent units is obtained. The probable cause of it is to be determined.

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; that is, every term in the equation will have the same unit.

Discussion Obviously this error was caused by forgetting to multiply the last term by mass at an earlier stage.

EXAMPLE 1–2

A tank is filled with oil whose density is ρ =850 kg/m^3. If the volume of the tank is V= 2 m^3, determine the amount of mass m in the tank.



Solution The volume of an oil tank is given. The mass of oil is to be determined.
Assumptions Oil is an incompressible substance and thus its density is constant

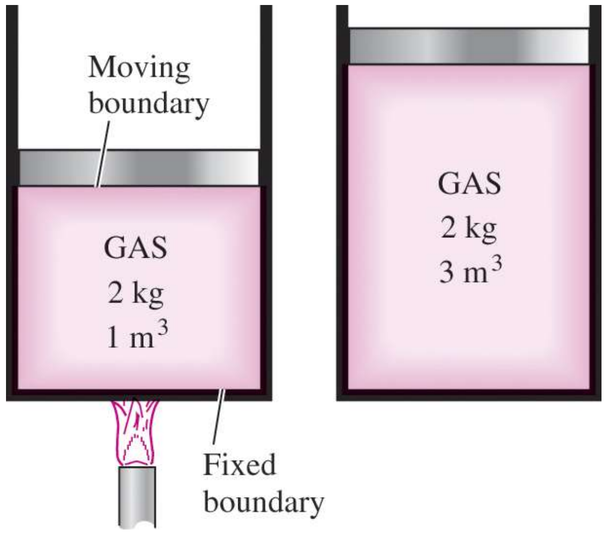
$$\rho = 850\ \text{kg/m}^3 \quad \text{and} \quad V = 2\ \text{m}^3$$

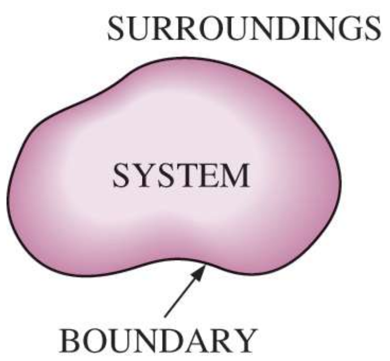
$$m = \rho V$$

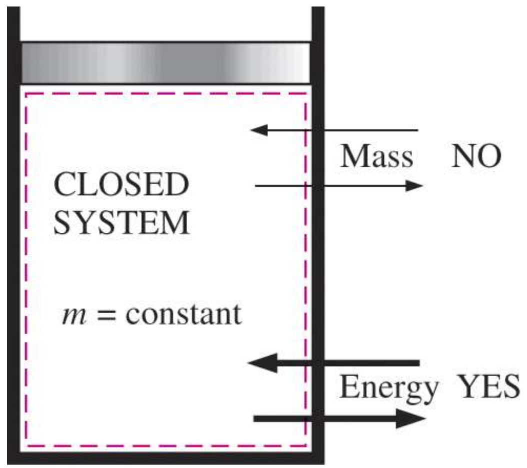
$$m = (850\ \text{kg/m}^3)(2\ \text{m}^3) = \mathbf{1700\ kg}$$

Discussion Note that this approach may not work for more complicated formulas.

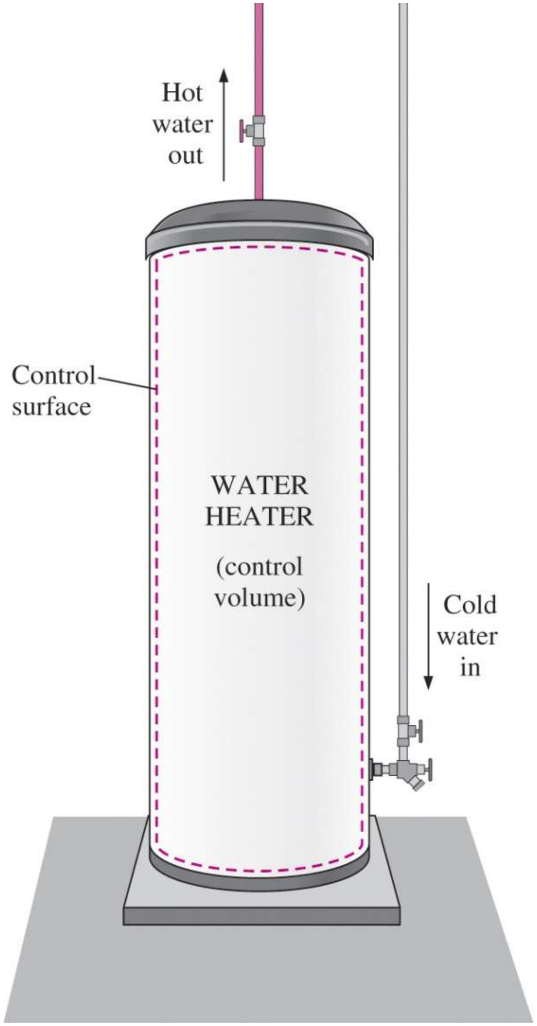
- **System**: A quantity of matter or a region in space chosen for study.
- **Surroundings**: The mass or region outside the system
- **Boundary**: The real or imaginary surface that separates the system from its surroundings.
- The boundary of a system can be *fixed* or *movable.*
- Systems may be considered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





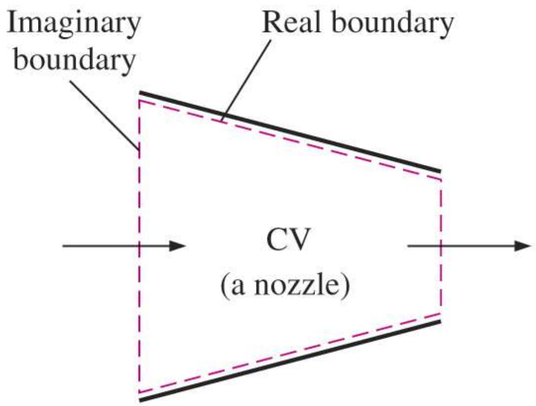


Closed system (Control mass): A fixed Amount of mass, and no mass can cross its boundary.

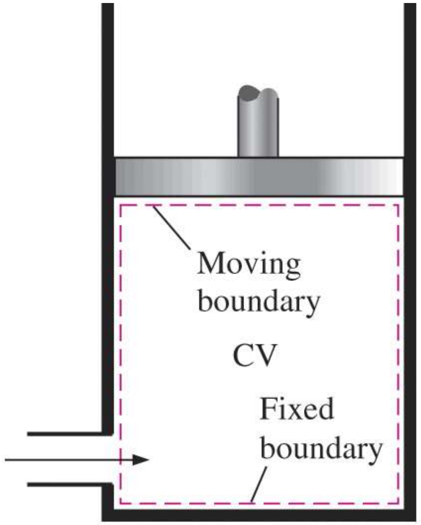


- **Open system (control volume)**: A properly selected region in space.
- It usually encloses a device that involves mass flow such as a compressor, turbine, or nozzle.
- Both mass and energy can cross the boundary of a control volume.
- **Control surface**: The boundaries of a control volume. It can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

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

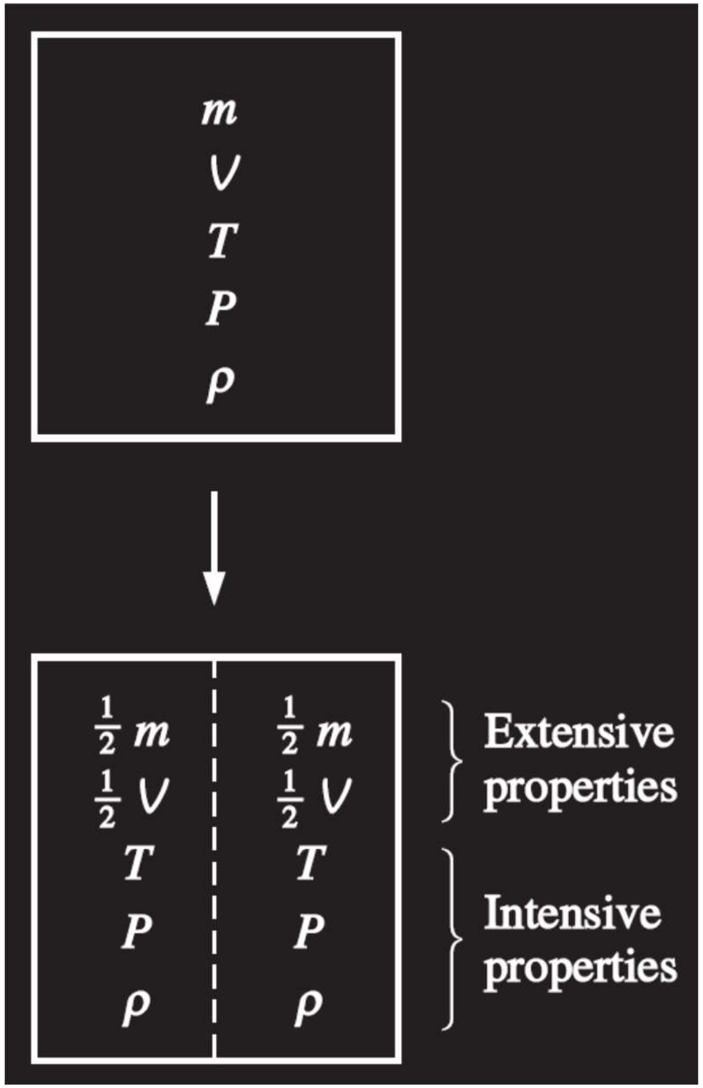


(*a*) A control volume with real and imaginary boundaries



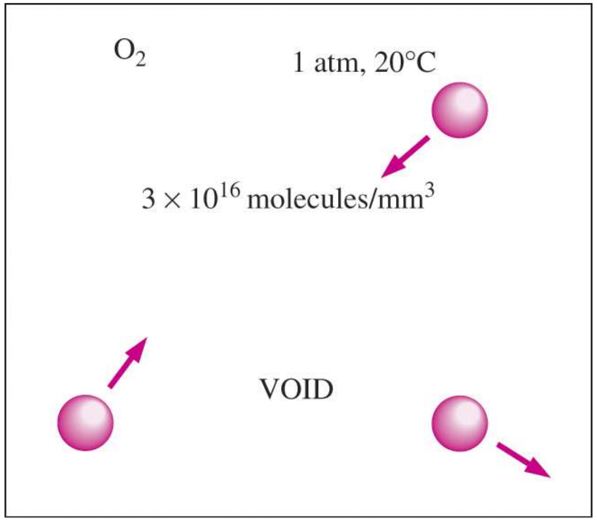
(*b*) A control volume with fixed and moving boundaries

- **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.

- Matter is made up of atoms that are widely spaced in the gas phase.
- It is very convenient to disregard the atomic nature of a substance and view it as a continuous, homogeneous matter with no holes, that is, a **continuum**.
- The continuum idealization allows us to treat properties as point functions and to assume the properties vary continually in space with no jump discontinuities.
- This idealization is valid as long as the size of the system we deal with is large relative to the space between the molecules.
- This is the case in practically all problems.
- In this text we will limit our consideration to substances that can be modeled as a continuum.



Despite the large gaps between molecules, a substance can be treated as a continuum because of the very large number of molecules even in an extremely small volume.

DENSITY AND SPECIFIC GRAVITY

Density

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

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

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

Specific volume

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

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

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

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).

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

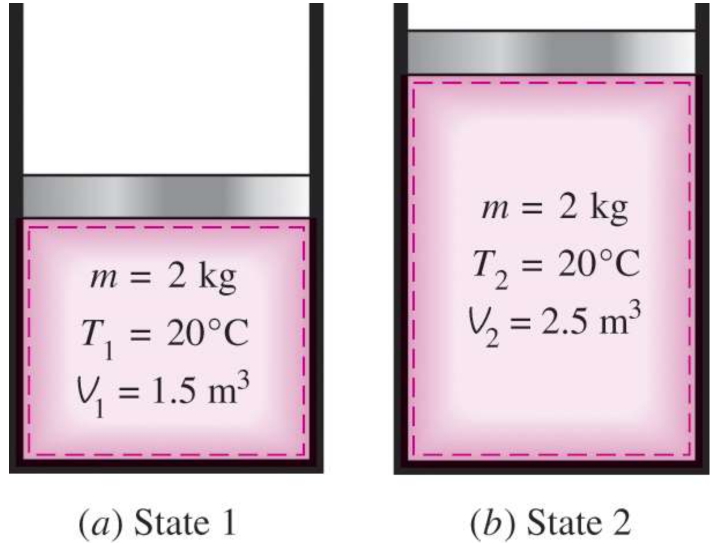
Specific gravities of some substances at 0°C

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

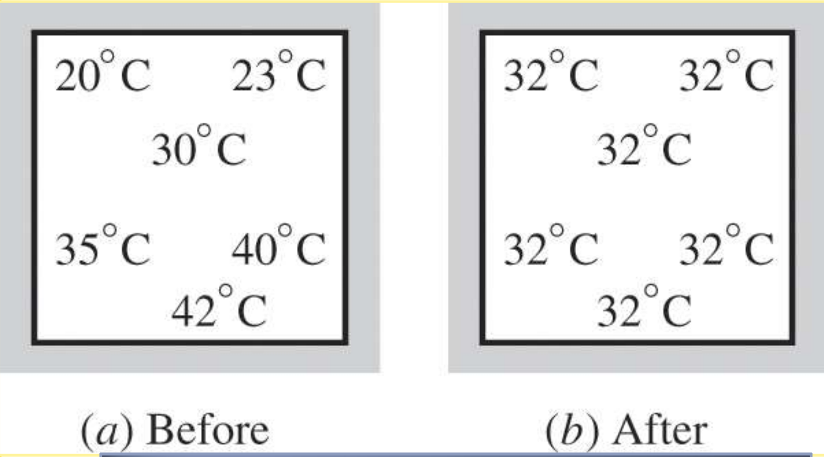
STATE AND EQUILIBRIUM

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.

- 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.

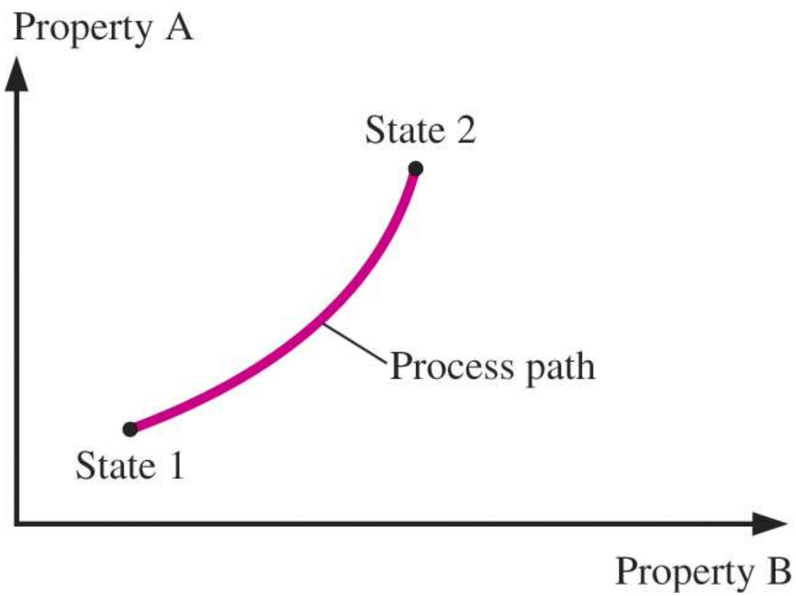
PROCESSES AND CYCLES

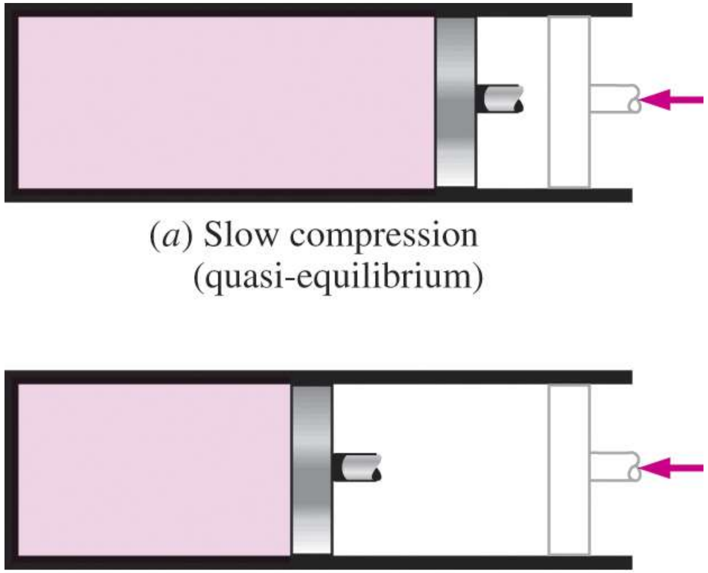
Process: Any change that a system undergoes from one equilibrium state to another.

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

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.

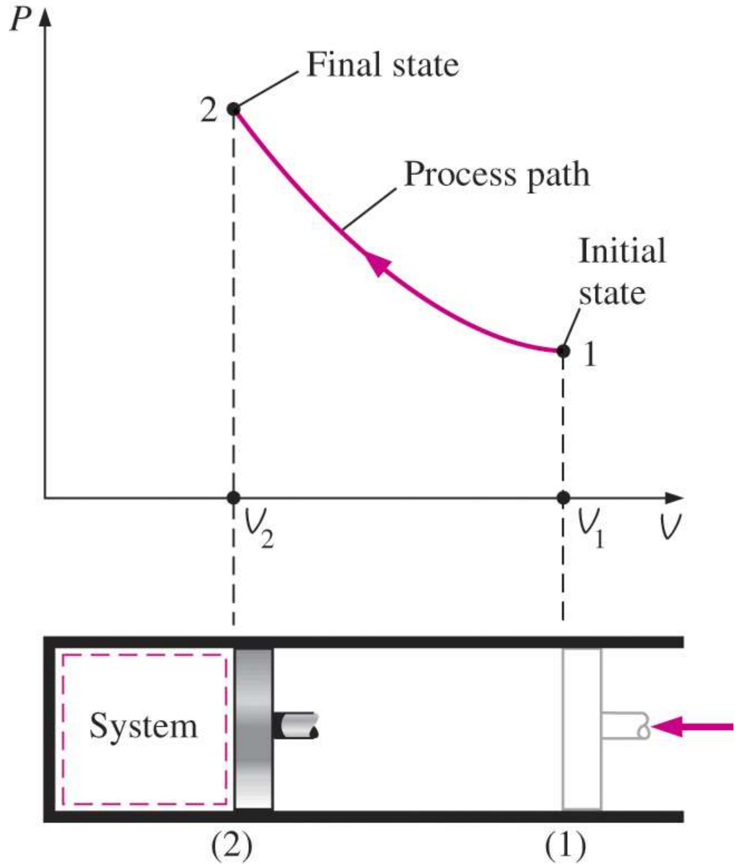




(*a*) Slow compression (quasi-equilibrium)

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

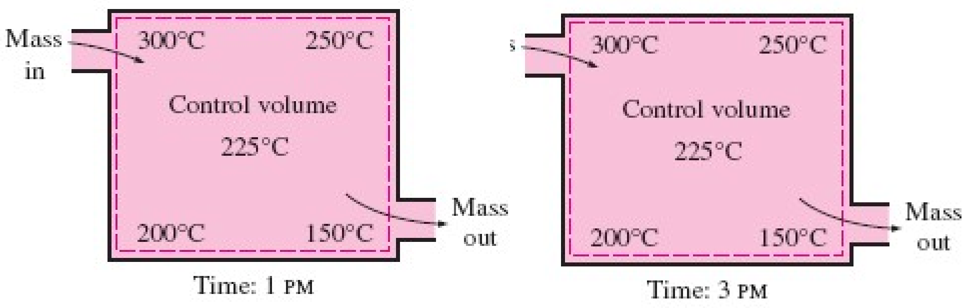
- Process diagrams plotted by employing thermodynamic properties as coordinates are very useful in visualizing the processes.
- Some common properties that are used as coordinates are temperature *T*, pressure *P*, and volume *V* (or specific volume *v*).
- The prefix *iso-* is often used to designate 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.
- **Cycle**: A process during which the initial and final states are identical.



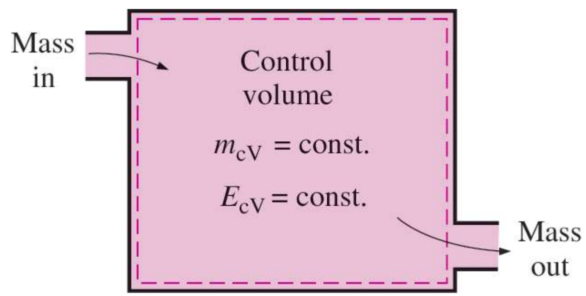
The *P-V* diagram of a compression process.

THE STEADY-FLOW PROCESS

- The term ***steady*** implies ***no change with time***. The opposite of steady is ***unsteady***, or ***transient***.
- A large number of engineering devices operate for long periods of time under the same conditions, and they are classified as ***steady-flow devices***.
- **Steady-flow process**: A process during which a fluid flows through a control volume steadily.
- Steady-flow conditions can be closely approximated by devices that are intended for continuous operation such as **turbines, pumps, boilers, condensers, and heat exchangers or power plants or refrigeration systems.**



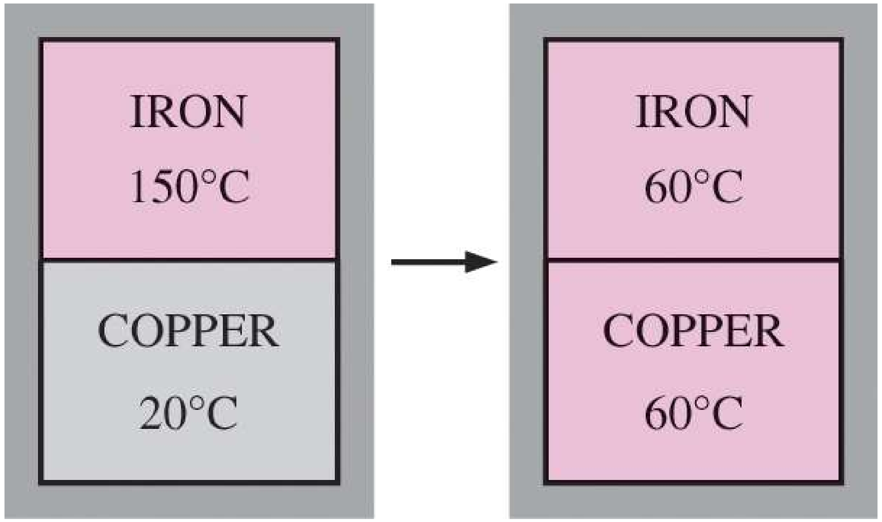
During a steady-flow process, fluid properties within the control volume may change with position but not with time.



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

- **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 a

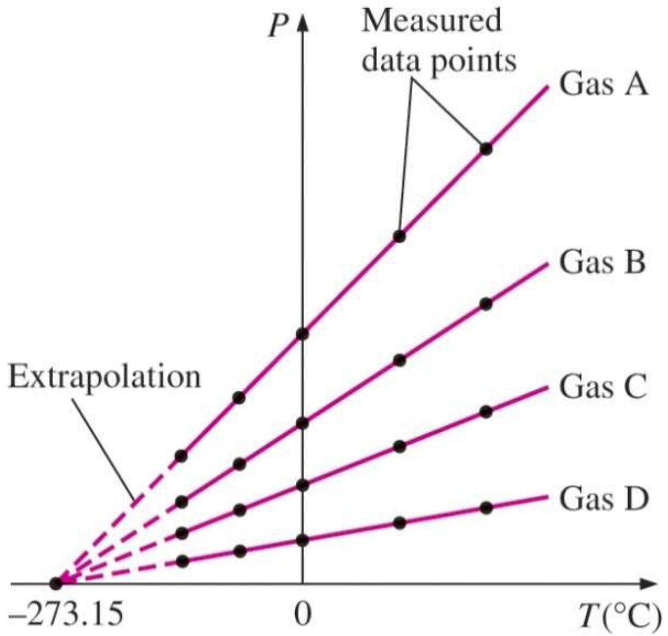
two bodies are in thermal equilibrium if both have the same temperature reading even if they are not in contact.

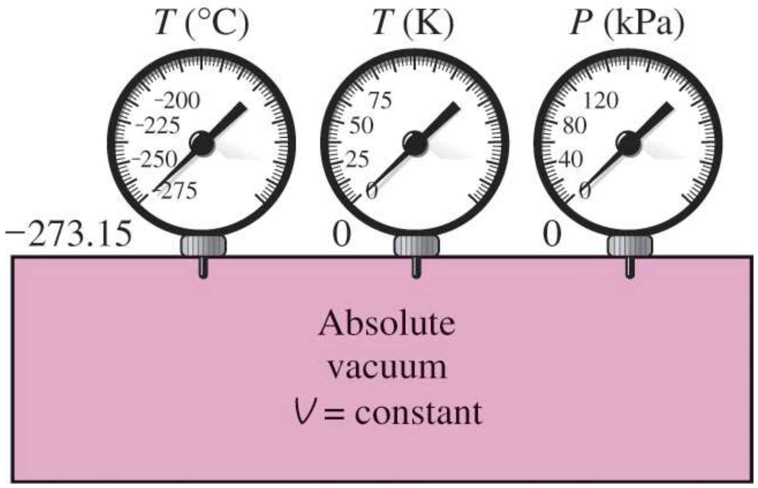


Two bodies reaching thermal equilibrium after being brought into contact in an isolated enclosure.

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.*
- **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).
- **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.
- **Kelvin scale** (SI) **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.

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

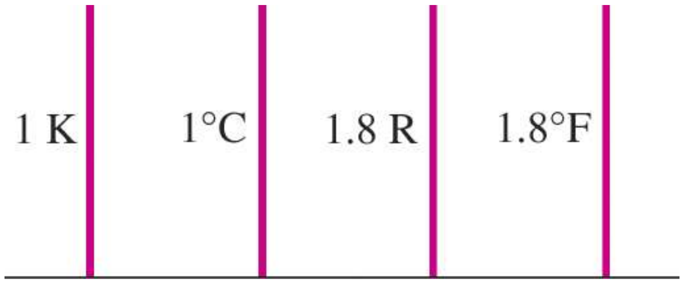
$$T(\mathrm{R}) = T(°\mathrm{F}) + 459.67$$

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

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

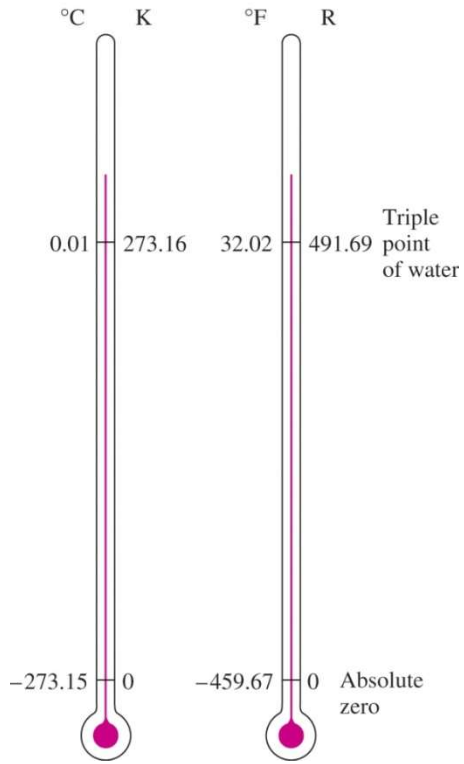
$$\Delta T(\mathrm{K}) = \Delta T(°\mathrm{C})$$

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



Comparison of magnitudes of various temperature units.

- The reference temperature in the original Kelvin scale was the ***ice point***, 273.15 K, which is the temperature at which water freezes (or ice melts).
- The reference point was changed to a much more precisely reproducible point, the ***triple point*** of water (the state at which all three phases of water coexist in equilibrium), which is assigned the value 273.16 K.



Comparison of temperature scales.

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

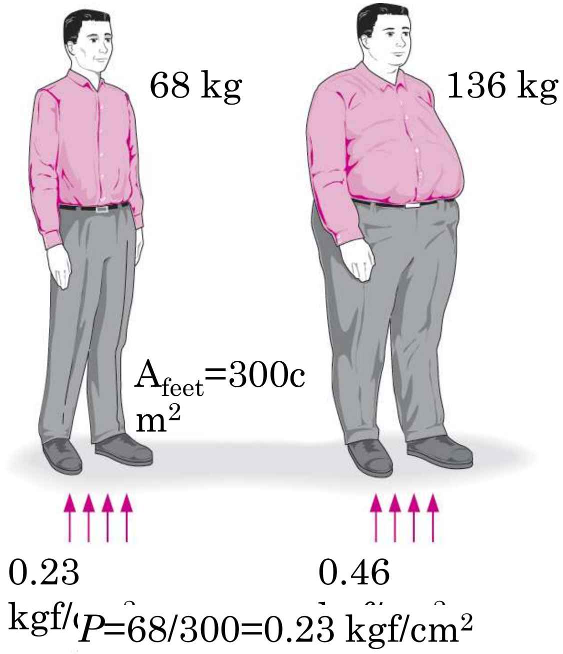
$$1\ \text{Pa} = 1\ \text{N/m}^2$$

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

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

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

Some basic pressure gages.

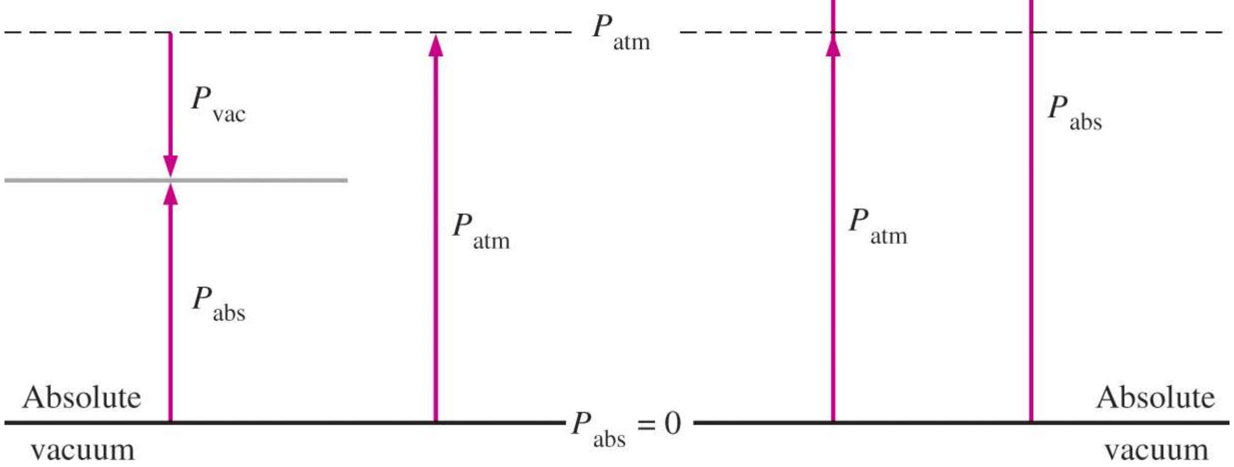


The normal stress (or "pressure") on the feet of a chubby person is much greater than on the feet of a slim person.

- **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.

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

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



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

EXAMPLE 1–5

A vacuum gage connected to a chamber reads 40 kPa at a location where the atmospheric pressure is 100 kPa. Determine the absolute pressure in the chamber.

Solution The gage pressure of a vacuum chamber is given. The absolute pressure in the chamber is to be determined.

Analysis The absolute pressure is easily determined from.

$$P_{abs} = P_{at}m - P_{vac} = 100 - 40 = 60 \text{ kPa}$$

Discussion Note that the local value of the atmospheric pressure is used when determining the absolute pressure.

Assuming the density of the fluid to be constant,
a force balance in the vertical *z*-direction gives;

$$\sum F_z = ma_z = 0: \qquad P_2\,\Delta x - P_1\,\Delta x - \rho g\,\Delta x\,\Delta z = 0$$

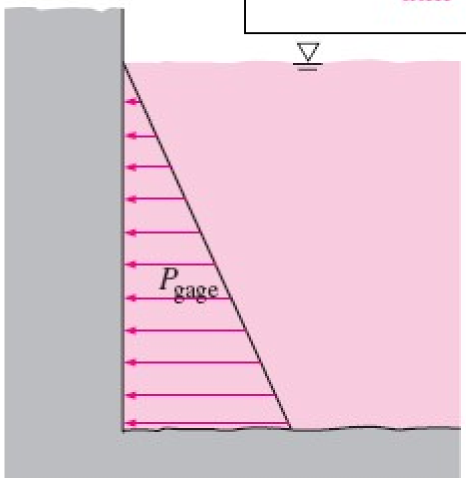
$$W = mg = \rho g\,\Delta x\,\Delta z$$

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

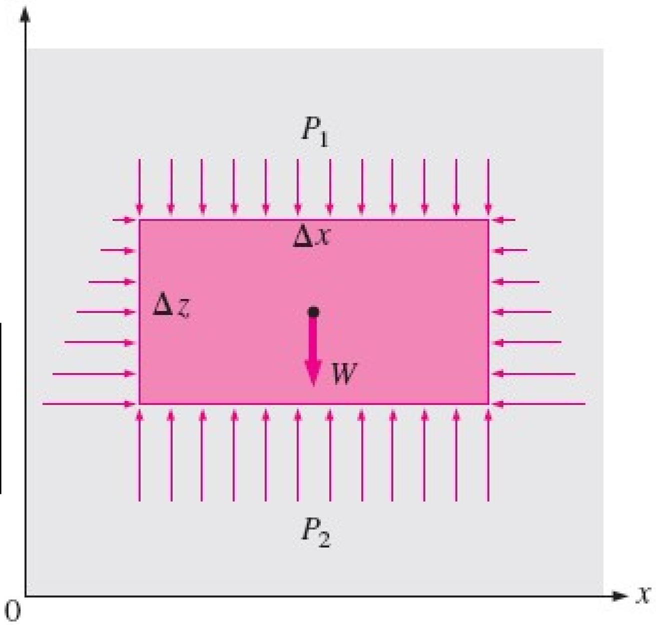
$$P = P_{atm} + \rho g h \qquad \text{or} \qquad P_{gage} = \rho g h$$

$$\frac{dP}{dz} = -\rho g$$

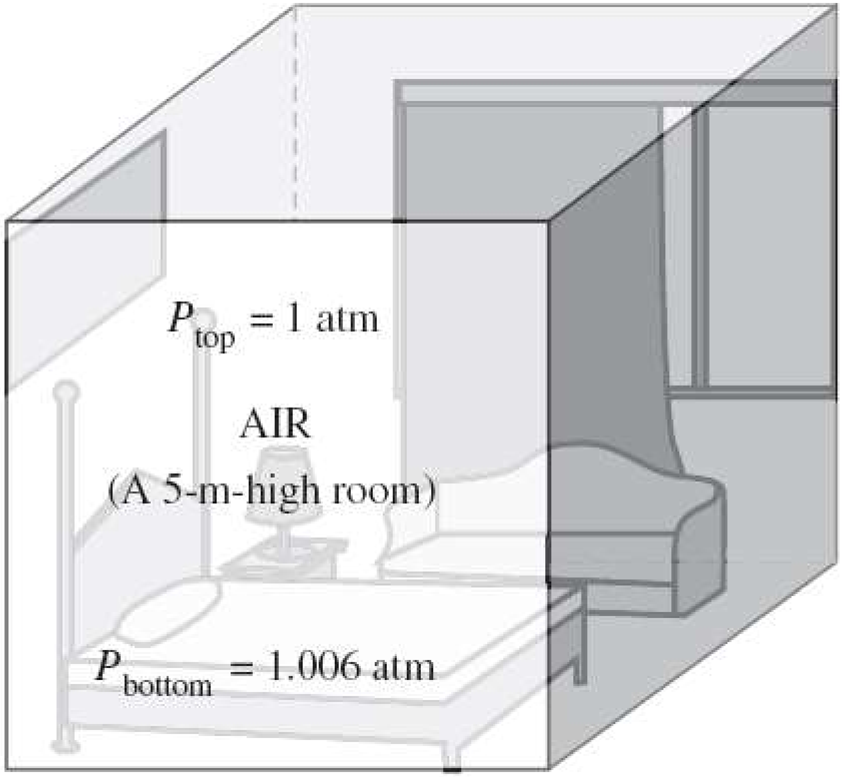
$$\Delta P = P_2 - P_1 = -\int_1^2 \rho g\,dz$$



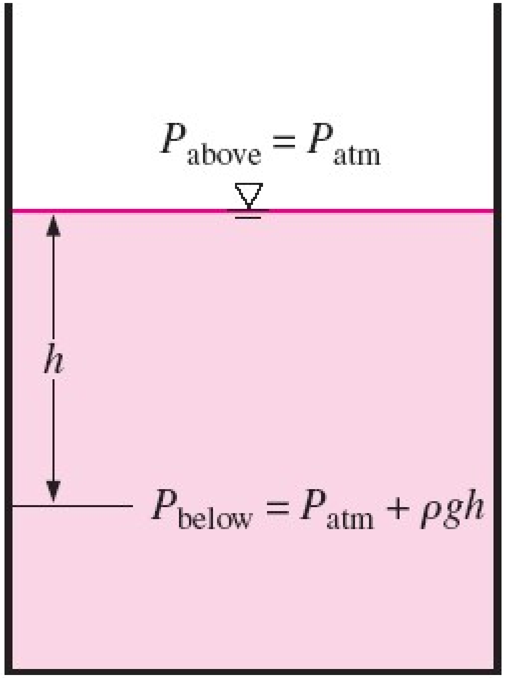
The pressure of a fluid at rest increases with depth (as a result of added weight).



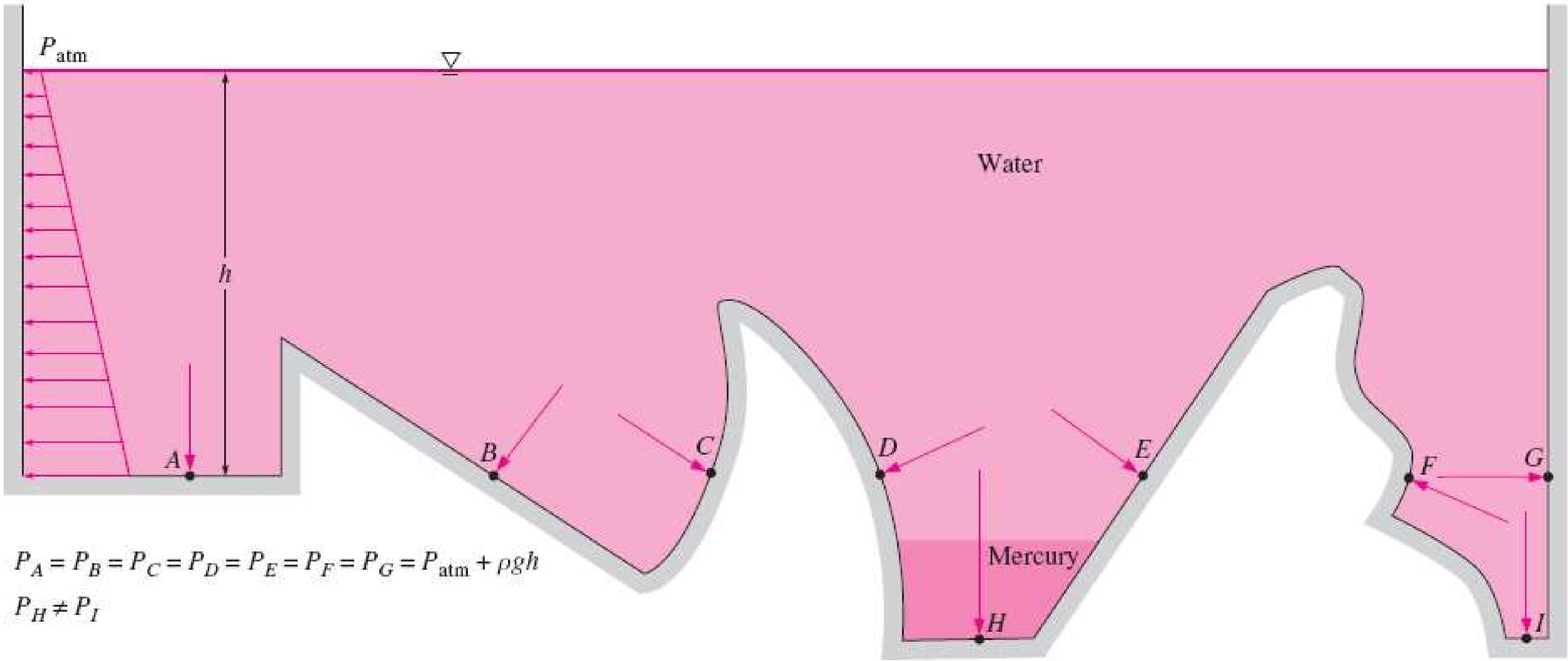
Free-body diagram of a rectangular fluid element in equilibrium.



In a room filled with a gas, the variation of pressure with height is negligible.



Pressure in a liquid at rest increases linearly with distance from the free surface.



The pressure is the same at all points on a horizontal plane in a given fluid regardless of geometry, provided that the points are interconnected by the same fluid.

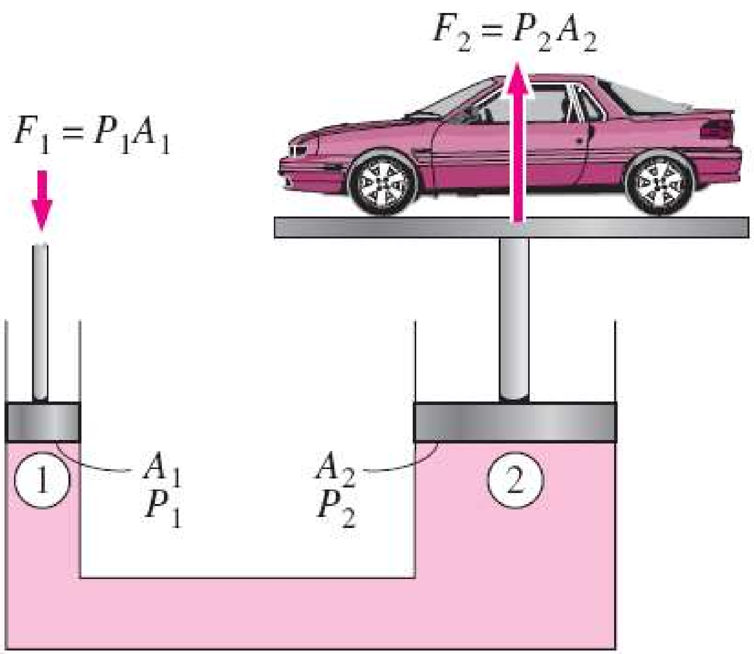
Pascal's law: The pressure applied to a confined fluid increases the pressure throughout by the same amount.

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

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

Using a hydraulic car jack with a piston area ratio of $A_2/A_1 = 10$,

For example, a person can lift a 1000-kg car by applying a force of just 100 kgf (=908 N)

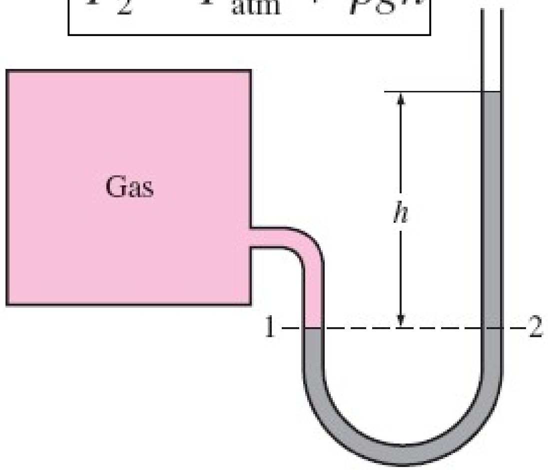


Lifting of a large weight by a small force by the application of Pascal's law.

THE MANOMETER

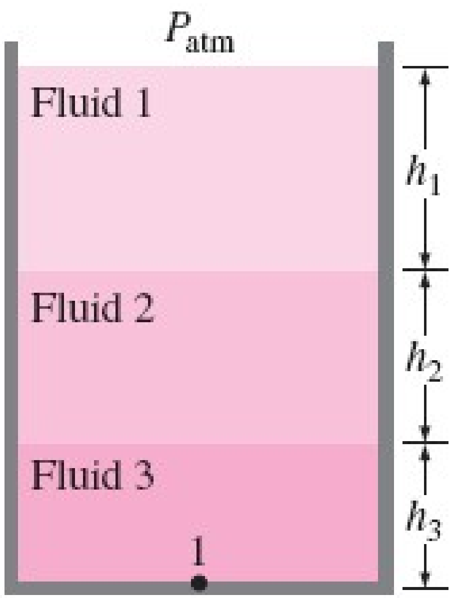
It is commonly used to measure small and moderate pressure differences. A manometer contains one or more fluids such as mercury, water, alcohol, or oil.

$$P_2 = P_{atm} + \rho g h$$

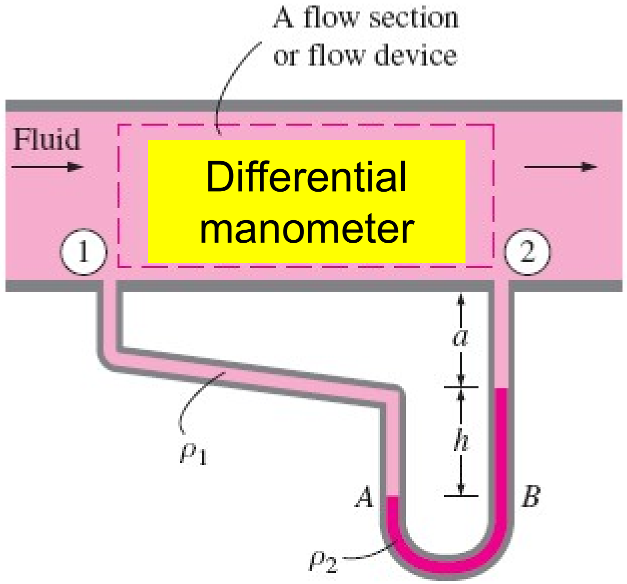


The basic manometer.

$$P_{atm} + \rho_1 g h_1 + \rho_2 g h_2 + \rho_3 g h_3 = P_1$$



In stacked-up fluid layers, the pressure change across a fluid layer of density ρ and height h is $\rho g h$.



Measuring the pressure drop across a flow section or a flow device

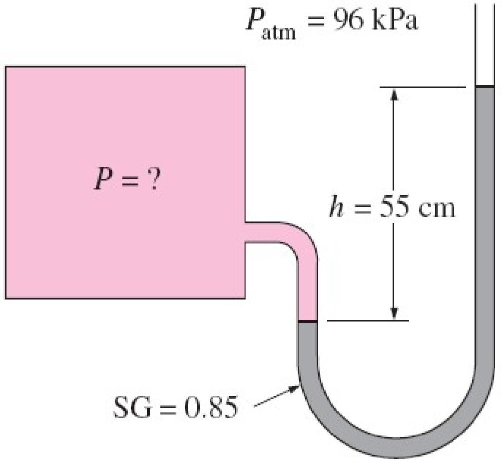
$$P_1 + \rho_1 g(a + h) - \rho_2 g h - \rho_1 g a = P_2$$

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

EXAMPLE 1–6

A manometer is used to measure the pressure in a tank. The fluid used has a specific gravity of 0.85, and the manometer column height is 55 cm. If the local atmospheric pressure is 96 kPa, determine the absolute pressure within the tank.

Solution The reading of a manometer attached to a tank and the atmospheric pressure are given. The absolute pressure in the tank is to be determined.
Assumptions The fluid in the tank is a gas whose density is much lower than the density of manometer fluid.
Properties The specific gravity of the manometer fluid is given to be 0.85. We take the standard density of water to be 1000 kg/m³.



$$\rho = \mathrm{SG}\,(\rho_{\mathrm{H_2O}}) = (0.85)(1000\ \mathrm{kg/m^3}) = 850\ \mathrm{kg/m^3}$$

$$P = P_{\mathrm{atm}} + \rho g h$$

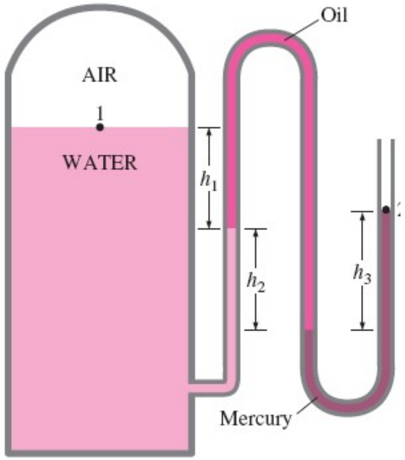
$$= 96\ \mathrm{kPa} + (850\ \mathrm{kg/m^3})(9.81\ \mathrm{m/s^2})(0.55\ \mathrm{m})\left(\frac{1\ \mathrm{N}}{1\ \mathrm{kg\cdot m/s^2}}\right)\left(\frac{1\ \mathrm{kPa}}{1000\ \mathrm{N/m^2}}\right)$$

$$= \mathbf{100.6\ kPa}$$

Discussion Note that the gage pressure in the tank is 4.6 kPa.

EXAMPLE 1–7

The water in a tank is pressurized by air, and the pressure is measured by a multifluid manometer. The tank is located on a mountain at an altitude of 1400 m where the atmospheric pressure is 85.6 kPa. Determine the air pressure in the tank if h_1=0.1 m, h_2= 0.2 m, and h_3=0.35 m. Take the densities ρ_{water}=1000 kg/m^3, ρ_{oil}= 850 kg/m^3, and $\rho_{mercury}$= 13,600 kg/m^3, respectively.



Solution The pressure in a pressurized water tank is measured by a multifluid manometer. The air pressure in the tank is to be determined.
Assumption The air pressure in the tank is uniform (i.e., its variation with elevation is negligible due to its low density), and thus we can determine the pressure at the air–water interface.

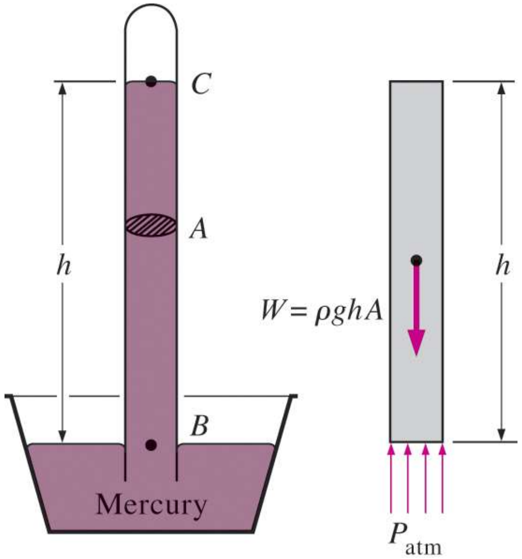
$$P_1 + \rho_{\text{water}} g h_1 + \rho_{\text{oil}} g h_2 - \rho_{\text{mercury}} g h_3 = P_{\text{atm}}$$

$$\begin{aligned}
P_1 &= P_{\text{atm}} - \rho_{\text{water}} g h_1 - \rho_{\text{oil}} g h_2 + \rho_{\text{mercury}} g h_3 \\
&= P_{\text{atm}} + g(\rho_{\text{mercury}} h_3 - \rho_{\text{water}} h_1 - \rho_{\text{oil}} h_2) \\
&= 85.6\ \text{kPa} + (9.81\ \text{m/s}^2)[(13{,}600\ \text{kg/m}^3)(0.35\text{m}) - 1000\ \text{kg/m}^3)(0.1\ \text{m}) \\
&\quad - (850\ \text{kg/m}^3)(0.2\ \text{m})]\left(\frac{1\ \text{N}}{1\ \text{kg}\cdot\text{m/s}^2}\right)\left(\frac{1\ \text{kPa}}{1000\ \text{N/M}^2}\right) \\
&= \mathbf{130\ kPa}
\end{aligned}$$

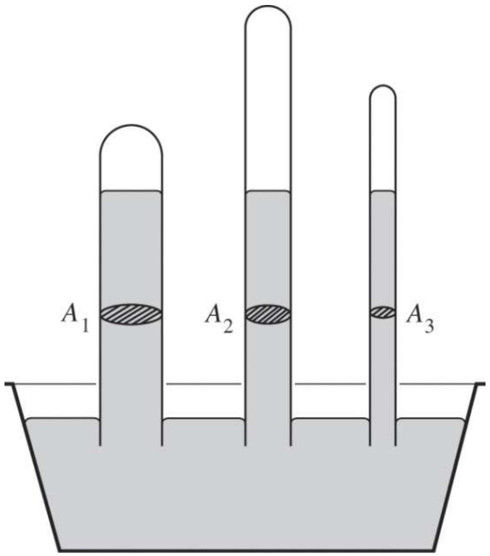
THE BAROMETER AND ATMOSPHERIC PRESSURE

- 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 (ρ_{Hg} = 13,595 kg/m^3) under standard gravitational acceleration (g = 9.807 m/s^2).

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



The basic barometer.



The length or the cross-sectional area of the tube has no effect on the height of the fluid column of a barometer, provided that the tube diameter is large enough to avoid surface tension (capillary) effects.

EXAMPLE 1–8

Determine the atmospheric pressure at a location where the barometric reading is 740 mm Hg and the gravitational acceleration is g=9.81 m/s^2. Assume the temperature of mercury to be 10^{0}C, at which its density is 13,570 kg/m^3.

Solution The barometric reading at a location in height of mercury column is given. The atmospheric pressure is to be determined.

Assumptions The temperature of mercury is assumed to be 10^{0}C.

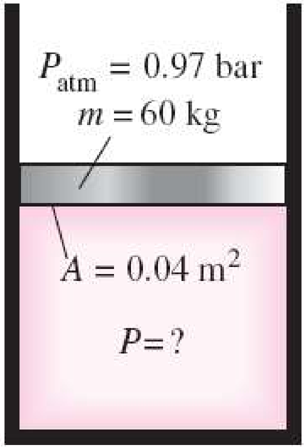
Properties The density of mercury is given to be 13,570 kg/m^3.

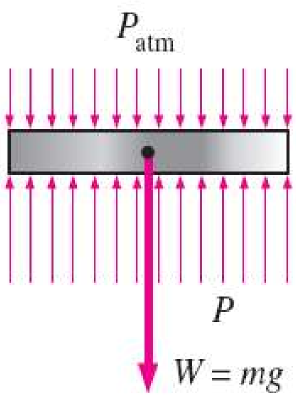
$$
\begin{aligned}
P_{\text{atm}} &= \rho g h \\
&= (13{,}570\ \text{kg/m}^3)(9.81\ \text{m/s}^2)(0.74\ \text{m})\left(\frac{1\ \text{N}}{1\ \text{kg}\cdot\text{m/s}^2}\right)\left(\frac{1\ \text{kPa}}{1000\ \text{N/m}^2}\right) \\
&= \mathbf{98.5\ kPa}
\end{aligned}
$$

Discussion Note that density changes with temperature, and thus this effect should be considered in calculations.

EXAMPLE 1–9

The piston of a vertical piston–cylinder device containing a gas has a mass of 60 kg and a cross-sectional area of 0.04 m^2. The local atmospheric pressure is 0.97 bar, and the gravitational acceleration is 9.81 m/s^2. (*a*) Determine the pressure inside the cylinder. (*b*) If some heat is transferred to the gas and its volume is doubled, do you expect the pressure inside the cylinder to change?





Solution A gas is contained in a vertical cylinder with a heavy piston. The pressure inside the cylinder and the effect of volume change on pressure are to be determined.

Assumptions Friction between the piston and the cylinder is negligible.

(*a*) Determine the pressure inside the cylinder

$$PA = P_{atm}A + W \qquad P = P_{atm} + \frac{mg}{A}$$

$$= 0.97\ \text{bar} + \frac{(60\ \text{kg})(9.81\ \text{m/s}^2)}{(0.04\ \text{m}^2)}\left(\frac{1\ \text{N}}{1\ \text{kg}\cdot\text{m/s}^2}\right)\left(\frac{1\ \text{kPa}}{10^5\ \text{N/m}^2}\right) = \mathbf{1.12\ bars}$$

(*b*) The volume change will have no effect on the free-body diagram drawn in part (*a*), and therefore the pressure inside the cylinder will remain the same.

Discussion If the gas behaves as an ideal gas, the absolute temperature doubles when the volume is doubled at constant pressure.

PROBLEM-SOLVING TECHNIQUE

- Step 1: Problem Statement
- Step 2: Schematic
- Step 3: Assumptions and Approximations
- Step 4: Physical Laws
- Step 5: Properties
- Step 6: Calculations
- Step 7: Reasoning, Verification, and Discussion

EES (Engineering Equation Solver) (Pronounced as ease): EES is a program that solves systems of linear or nonlinear algebraic or differential equations numerically. It has a large library of built-in thermodynamic property functions as well as mathematical functions. Unlike some software packages, EES does not solve engineering problems; it only solves the equations supplied by the user.

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
- The manometer and the atmospheric pressure
- Problem solving technique