Chapter one

Basic Concepts of Thermodynamics

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 that will be used throughout the text.
- Explain the basic concepts of thermodynamics such as system, state, equilibrium, process, and cycle.
- Review concepts of temperature, temperature scales, pressure, and absolute presseure,gage pressure and vacuum pressure.

Definition

Thermodynamics

is the science primarily deals with energy.

stems from the Greek word ,thermo(heat) and dynamics(power)

The first law of thermodynamics is simply an expression of the conservation of energy principle, and it asserts that energy is a thermodynamic property.

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

APPLICATION AREA

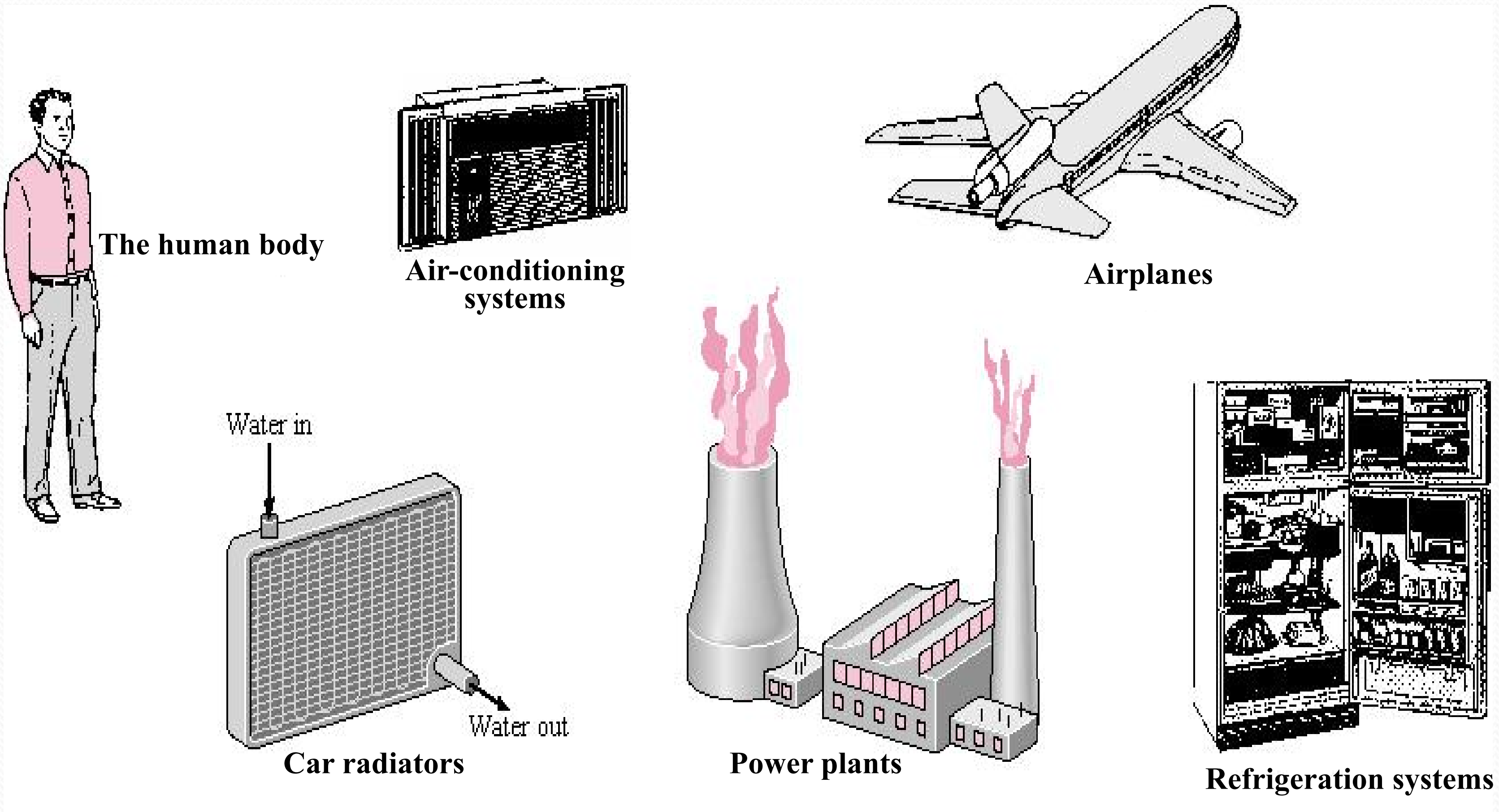
All activities in nature involve some interaction between energy and matter; thus, it is hard to imagine an area that does not relate to thermodynamics in some manner. Therefore, developing a good understanding of basic principles of thermodynamics has long been an essential part of engineering education.

examples

include the electric or gas range, the heating and air-conditioning systems, the refrigerator, the humidifier, the pressure cooker, the water heater, the shower, and even the computer and the TV.

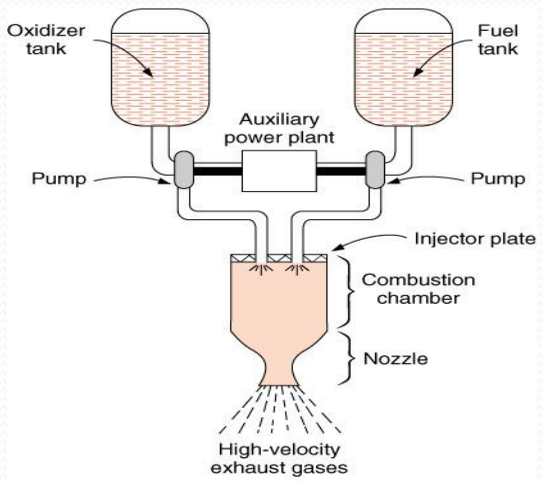
the design and analysis of automotive engines, rockets, jet engines, and conventional or nuclear power plants, solar collectors, and the design of vehicles from ordinary cars to airplanes.

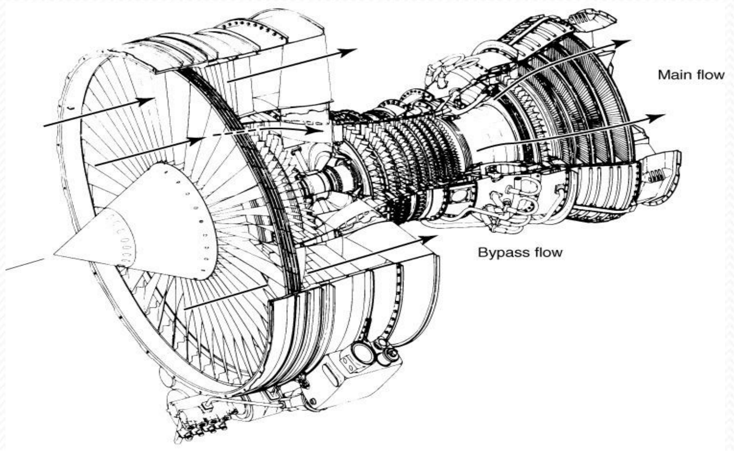
CONTI.

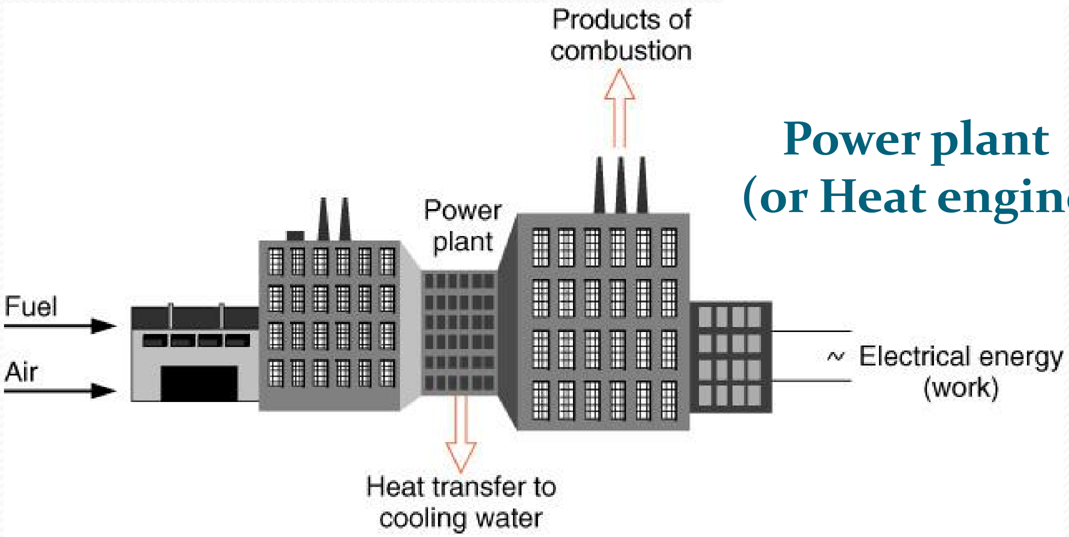


The human body
Air-conditioning systems
Airplanes
Water in
Water out
Car radiators
Power plants
Refrigeration systems

CONTI.







Power plant
(or Heat engine

Dimension and unit system

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.

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)

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

Systems and Control Volume (Closed and Open Systems)

Thermodynamic System

is defined as a quantity of matter or a region in space chosen for study.

Surroundings

Everything external to the system (the mass or region outside the system).

Boundary

- is Surface that separates the system from the surroundings. It may be **fixed** or **movable, real or imaginary.**
- is contact surface shared by both the system and the surroundings.
- Mathematically speaking, the boundary has zero thickness, and thus it can neither contain any mass nor occupy any volume in space.

CONTI.

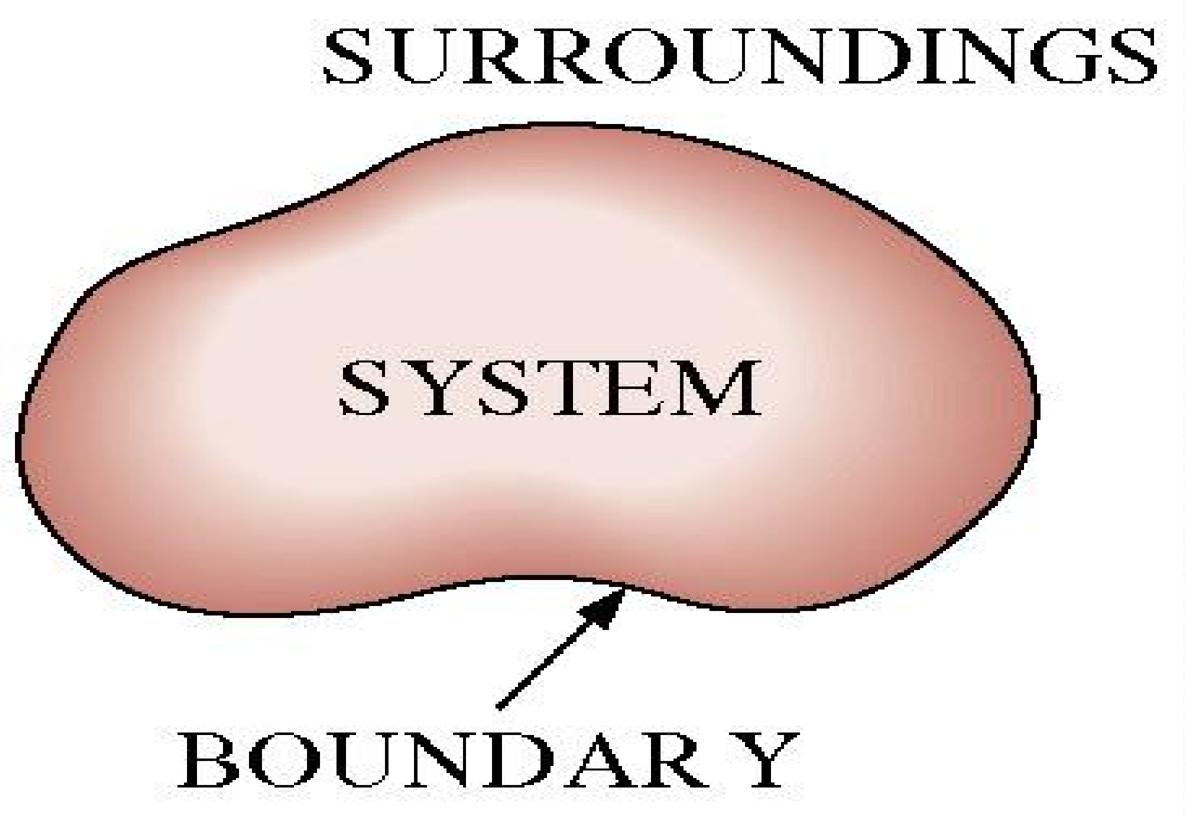


Fig. System, surroundings, and boundary.

CONTI.

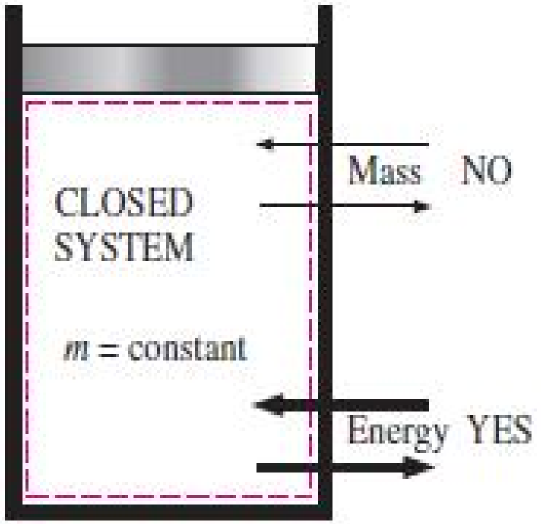
Systems may be considered as

- closed system(control mass)
- open system (control volume)

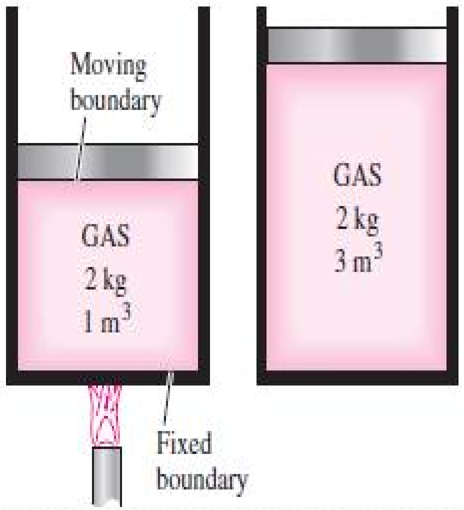
depending on whether a fixed mass or a fixed volume in space is chosen for study.

A **closed system** (also known as a **control mass) consists of a fixed amount of mass, and no** mass can cross its boundary. That is, no mass can enter or leave a closed system, as shown in fig. below. But energy, in the form of heat or work, can cross the boundary; and the volume of a closed system does not have to be fixed. If, as a special case, even energy is not allowed to cross the boundary, that system is called an **isolated system.**

Conti.



Mass cannot cross the boundaries of a closed system, but energy can.



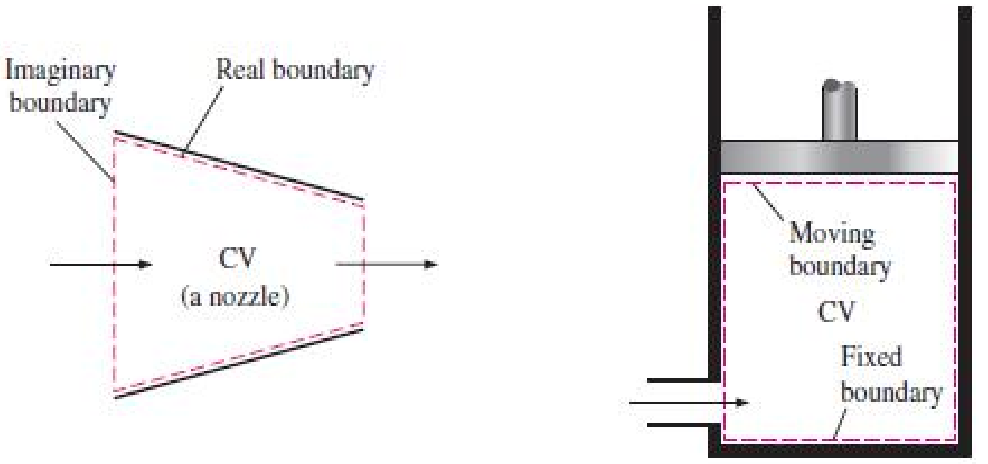
A closed system with a moving boundary.

Conti.

open system (a control volume)

- Both mass and energy can cross the boundary of control volume.
- It usually encloses a device that involves mass flow such as a compressor, turbine, or nozzle.

Conti.



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

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

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

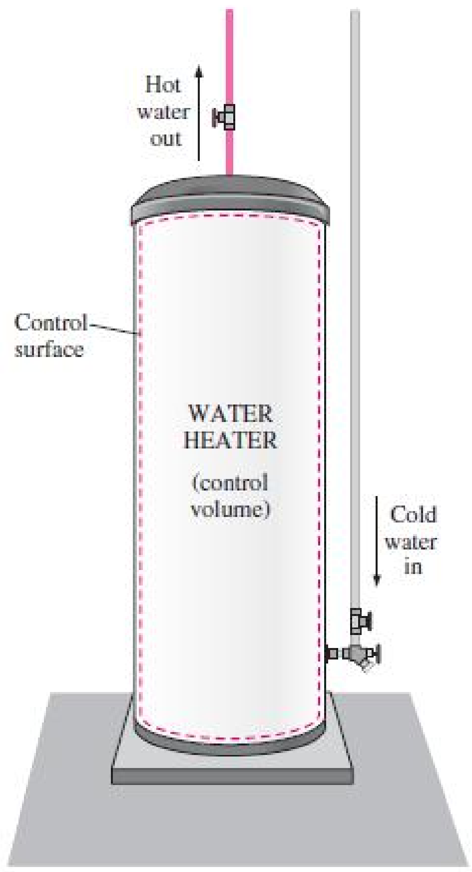


FIGURE 1–19

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

Properties of a system

Any characteristic of a system is called a **property.**

Example: pressure (P), temperature(T), volume(V), and mass(m)

Properties are considered to be either **intensive or extensive**

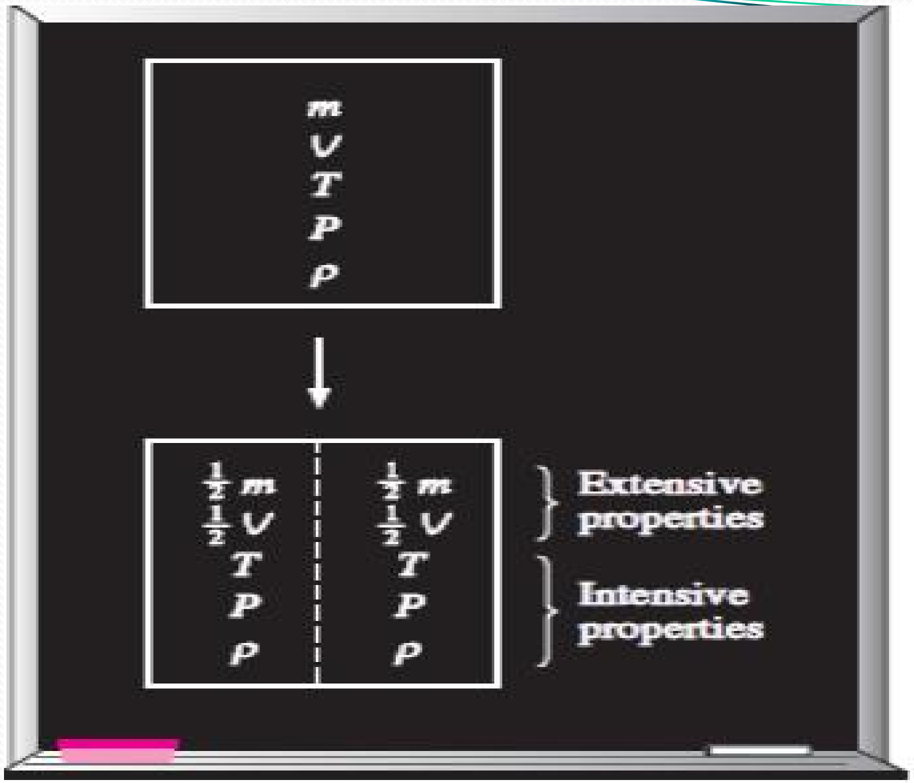
Intensive properties are those that are independent of the mass of a system, such as temperature, pressure, and density.

Extensive properties are those whose values depend on the size-or extent-of the system.

Total mass, total volume, and total momentum are some examples of extensive properties.

An easy way to determine whether a property is intensive or extensive is to divide the system into two equal parts with an imaginary partition, as shown in Fig. below. Each part will have the same value of intensive properties as the original system, but half the value of the extensive properties.

Conti.



Criterion to differentiate intensive and extensive properties.

Extensive properties per unit mass are called **specific properties.**

Some examples of specific properties are specific volume (v = V/m) and specific total energy (e =E/m).

DENSITY AND SPECIFIC GRAVITY

Density is defined as mass per unit volume

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

The reciprocal of density is the **specific volume** ***v*****, which is defined as volume** per unit mass. That is,

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

Sometimes the density of a substance is given relative to the density of a well-known substance. Then it is called **specific gravity, or relative density,** and is defined as *the ratio of the density of a substance to the density of some standard substance at a specified temperature* (usually water at 4°C, for which $\rho_{H_2O} = 1000$ kg/m³). That is,

Specific gravity: $$SG = \frac{\rho}{\rho_{H_2O}} \quad (1\text{–}6)$$

Note that the specific gravity of a substance is a dimensionless quantity.

Conti.

Note that substances with specific gravities less than 1 are lighter than water, and thus they would float on water.

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

The weight of a unit volume of a substance is called **specific weight and** is expressed as

Specific weight: $$\gamma_s = \rho g \qquad (\text{N/m}^3)$$

where g is the gravitational acceleration.

STATE AND EQUILIBRIUM

State

is the condition of the system which is described by a set of properties (e.g.Temperature,pressure…).

- At a given state, all the properties of a system have fixed values.
- If the value of even one property changes, the state will change to a different one

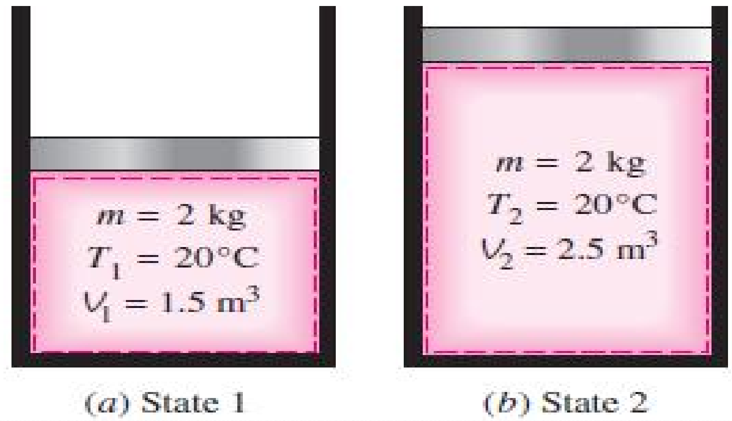


Fig. A system at two different states.

Conti.

Equilibrium

Thermodynamics deals with equilibrium states.

Equilibrium

- ✓ implies a state of balance.
- ✓ no unbalanced potentials (or driving forces) within the system.

There are many types of equilibrium, example

Thermal equilibrium

A system is in thermal equilibrium if the temperature is the same throughout the entire system

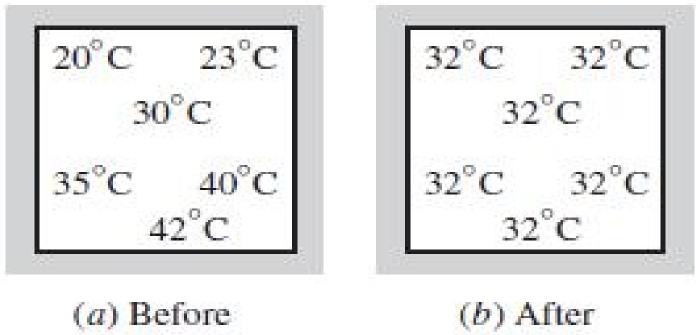


fig. A closed system reaching thermal equilibrium.

Conti.

Mechanical equilibrium

A system is in mechanical equilibrium if there is no change in pressure at any point of the system with time.

Phase equilibrium

A system involves two phases, it is in phase equilibrium when the mass of each phase reaches an equilibrium level and stays there.

chemical equilibrium

A system is in chemical equilibrium if its chemical composition does not change with time, that is, no chemical reactions occur.

N.B.A system will not be in equilibrium unless all the relevant equilibrium criteria are satisfied.

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 of the process, as well as the path it follows, and the interactions with the surroundings.

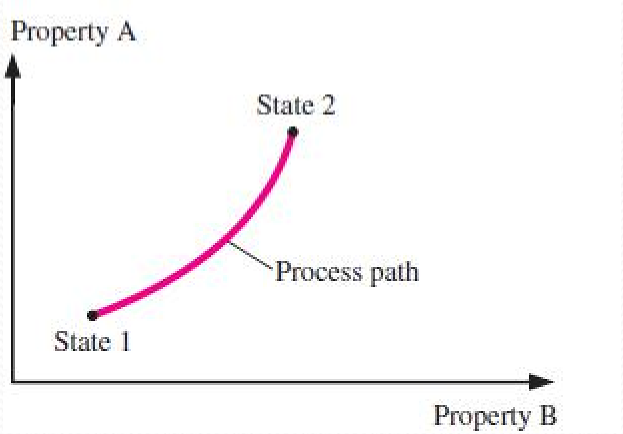


Fig. A process between states 1 and 2 and the process path.

CONTI.

The state of a system is defined when it is in equilibrium.

non-quasi-equilibrium process

If we change the state very fast it is not in equilibrium during the process **(non-quasi-equilibrium process)**

The system is not in equilibrium during the process. States during the process are undefined. We can only define the initial and final states.

quasi-static process or quasi-equilibrium process(is an ideal process)

If we change state slowly then the system is in equilibrium during the process **(quasi-static process or quasi-equilibrium process)**

The system is very near to equilibrium in all successive states during the process.

Fig.Quasi-equilibrium and non quasi-equilibrium compression processes.

Conti.

In thermodynamics, we have different processes, such as

Isothermal process

is a process during which the temperature T remains constant

Isobaric process

is a process during which the pressure P remains constant

Isochoric (or isometric) process

is a process during which the specific volume v remains constant.

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

A system is said to have undergone a cycle if it returns to its initial state at the end of the process. That is, for a cycle the initial and final states are identical.

CONTI.

Steady-Flow Process

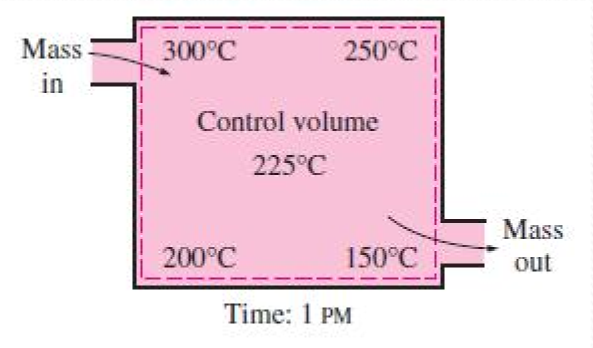
The terms steady and uniform are used frequently in engineering,

The term steady implies no change with time. The opposite of steady is unsteady, or transient.

The term uniform, however, implies no change with location over a specified region.

A large number of engineering devices operate for long periods of time under the same conditions, and they are classified as steady-flow devices. Processes involving such devices can be represented reasonably well by a somewhat idealized process, called the steady-flow process, which can be defined as a process during which a fluid flows through a control volume steadily . As shown in fig.below.

Conti.



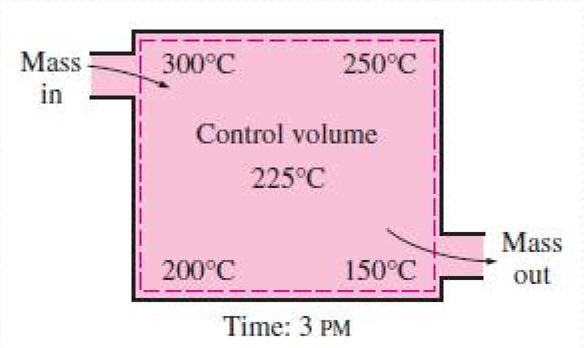


Fig. During a steady-flow process, fluid properties within the control volume may change with position but not with time

In steady flow device, the fluid properties can change from point to point within the control volume, but at any fixed point they remain the same during the entire process. Therefore, the volume V, the mass m, and the total energy content E of the control volume remain constant during a steady flow process as shown in the fig below.

Conti.

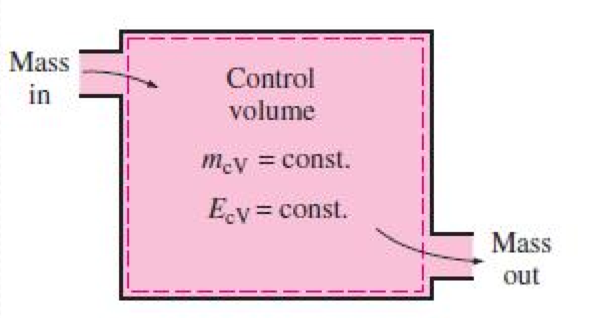


Fig. Under steady-flow conditions, the mass and energy contents of a control volume remain constant.

TEMPERATURE AND THE ZEROTH LAW OF THERMODYNAMICS

Temperature: Degree of hotness of coldness

The zeroth law of thermodynamics

states that if two bodies are in thermal equilibrium with a third body, they are also in thermal equilibrium with each other.

is one of the basic law of thermodynamics.

It cannot be concluded from the other laws of thermodynamics, and it serves as a basis for the validity of temperature measurement. 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.

CONTI.

- T_A

T_B

T_C

if $T_A = T_C$ & $T_B = T_C$

then $T_A = T_B$

Conti.

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

The temperature scales used in the SI and in the English system today are

- ✓ **Celsius scale**
- ✓ **Fahrenheit scale**

On the Celsius scale, the ice and steam points were originally assigned the values of 0 and 100°C,respectively.

The corresponding values on the Fahrenheit scale are 32 and 212°F.These are often referred to as two-point scales since temperature values are assigned at two different points.

Conti.

Thermodynamic(absolute) temperature scale

- is temperature scale that is independent of the properties of any substance or substances.
- The thermodynamic temperature scale in the SI is the Kelvin scale. The temperature unit on this scale is the Kelvin, which is designated by K (not °K).

  The lowest temperature on the Kelvin scale is absolute zero, or **O** K.
- ✓ Thermodynamic temperature scale in the English system is the Rankine scale. The temperature unit on this scale is the Rankine, which is designated by R.

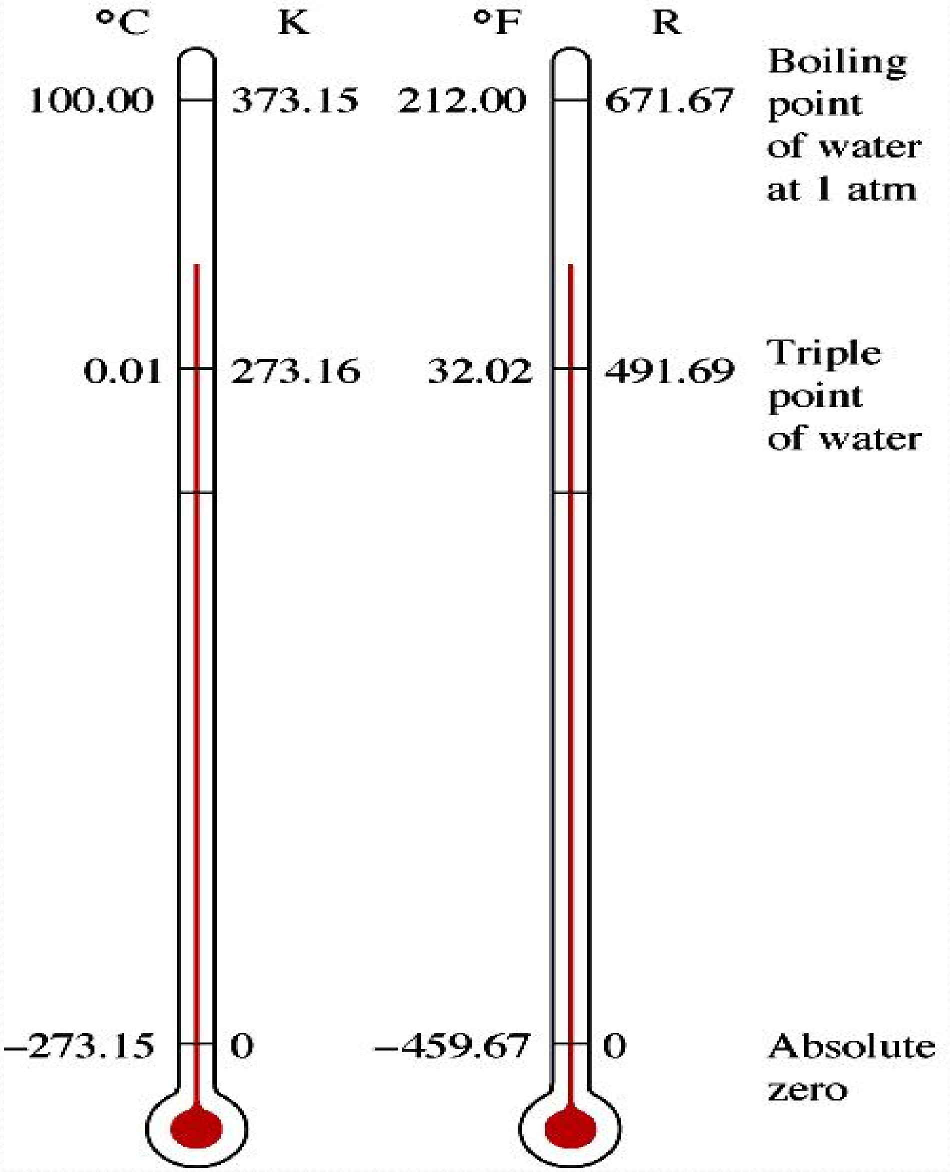
Conti.

The reference temperature chosen in the original Kelvin scale was 273.15 K (or 0°C), which is the temperature at which water freezes (or ice melts) and water exists as a solid–liquid mixture in equilibrium under standard atmospheric pressure (the ice 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(0.01°C).

The boiling temperature of water (the steam point) was experimentally determined to be again 100.00°C.

CONTI.



°C
K
°F
R
100.00
373.15
212.00
671.67
Boiling point of water at 1 atm
0.01
273.16
32.02
491.69
Triple point of water
–273.15
0
–459.67
0
Absolute zero

Conti.

The Kelvin scale is related to the Celsius scale by

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

The Rankine scale is related to the Fahrenheit scale by

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

The temperature scales in the two unit systems are related by

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

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

Conti.

When we are dealing with temperature differences T, the temperature interval on both scales is the same.

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

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

PRESSURE

Pressure is defined as a normal force exerted by a fluid per unit area.

We speak of pressure only when we deal with a gas or a liquid.

The counterpart of pressure in solids is *normal stress. Since pressure is defined as force per* unit area, it has the unit of Newton per square meter (N/m^2), which is called a Pascal (Pa). That is,

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

$$1 \text{ kPa} = 10^3 \text{ Pa}$$

$$1 \text{ MPa} = 10^6 \text{ Pa}$$

Conti.

Three other pressure units commonly used in practice, especially in Europe, are bar, standard atmosphere, and kilogram-force per square centimeter:

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

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

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

Note that the pressure units bar, atm, and kgf/cm^2 are almost equivalent to each other. In the English system, the pressure unit is *pound-force per square inch* (lbf/in^2, or psi), and 1 atm = 14.696 psi. The pressure units kgf/cm^2 and lbf/in^2 are also denoted by kg/cm^2 and lb/in^2, respectively, and they are commonly used in tire gages. It can be shown that $1 \text{ kgf/cm}^2 = 14.223$ psi.

Conti.

The actual pressure at a given position is called the **absolute pressure, and** it is measured relative to absolute vacuum (i.e., absolute zero pressure).

Most pressure-measuring devices, however, are calibrated to read zero in the atmosphere as shown in the fig. below, and so they indicate the difference between the absolute pressure and the local atmospheric pressure. This difference is called the **gage pressure.**

Pressures below atmospheric pressure are called vacuum pressures and are measured by vacuum gages that indicate the difference between the atmospheric pressure and the absolute pressure. Absolute, gage, and vacuum pressures are all positive quantities and are related to each other by

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

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

Conti.

Conti.

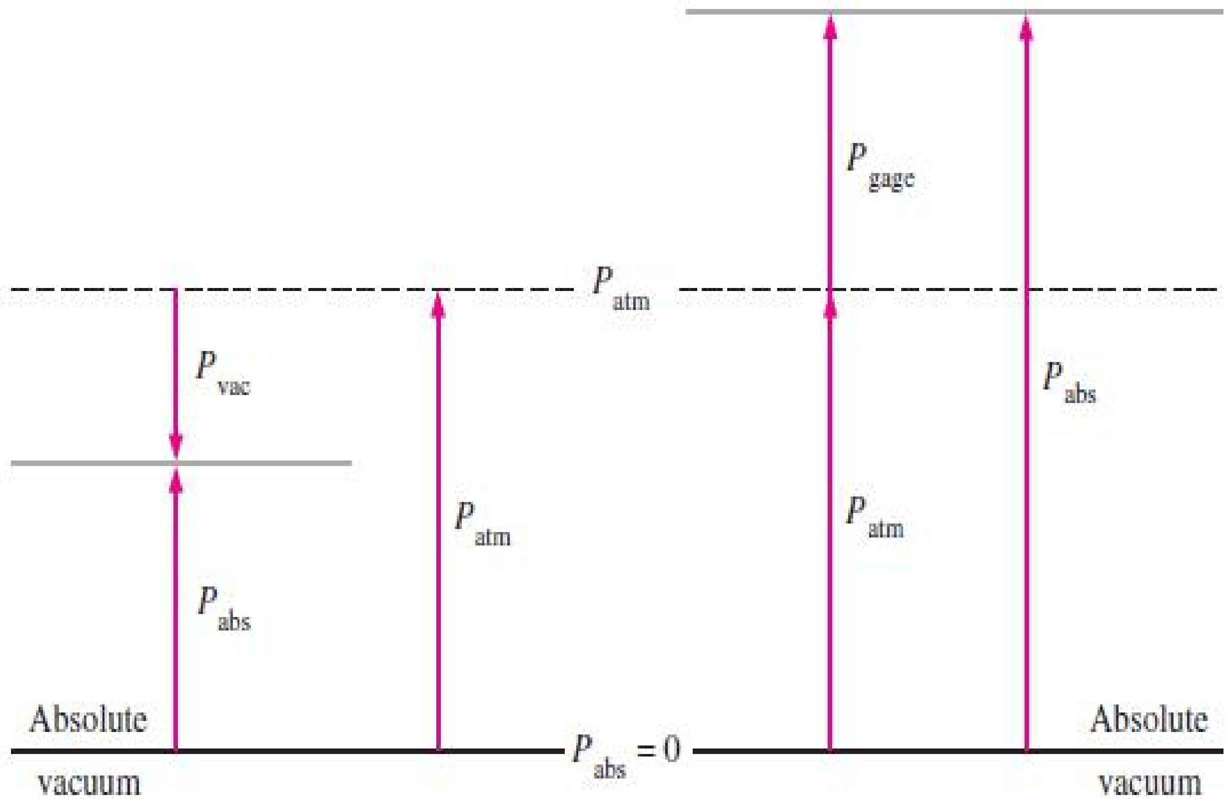


Fig. Absolute, gage, and vacuum pressures.

Variation of Pressure with Depth

Pressure in a fluid increases with depth because more fluid rests on deeper layers, and the effect of this "extra weight" on a deeper layer is balanced by an increase in pressure

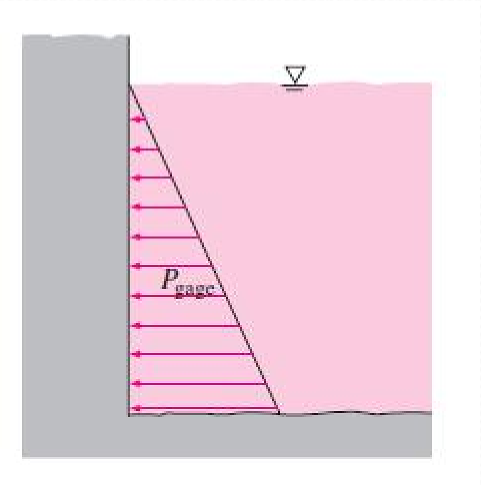


Fig. The pressure of a fluid at rest increases with depth (as a result of added weight).

Conti.

To prove,

consider a rectangular fluid element of height z, length x, and unit depth (into the page) in equilibrium, as shown in Fig. below. Assuming the density ρ of the fluid to be constant, a force balance in the vertical z-direction gives

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

where $W = mg = \rho g \, \Delta x \, \Delta z$ is the weight of the fluid element. Dividing by Δx and rearranging gives

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

where $\gamma_s = \rho g$ is the *specific weight* of the fluid.

Conti.

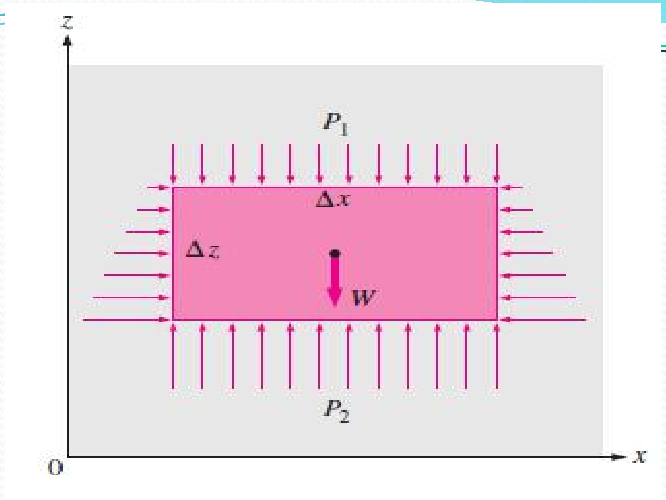


Fig. Free-body diagram of a rectangular fluid element in equilibrium.

The pressure difference between two points in a constant density fluid is proportional to the vertical distance z between the points and the density ρ of the fluid. In other words, pressure in a fluid increases linearly with depth. This is what a diver experiences when diving deeper in a lake. For a given fluid, the vertical distance z is sometimes used as a measure of pressure, and it is called the pressure head.

Conti.

For small to moderate distances, the variation of pressure with height is negligible for gases because of their low density. The pressure in a tank containing a gas, for example, can be considered to be uniform since the weight of the gas is too small to make a significant difference. Also, the pressure in a room filled with air can be assumed to be constant as shown in the fig.

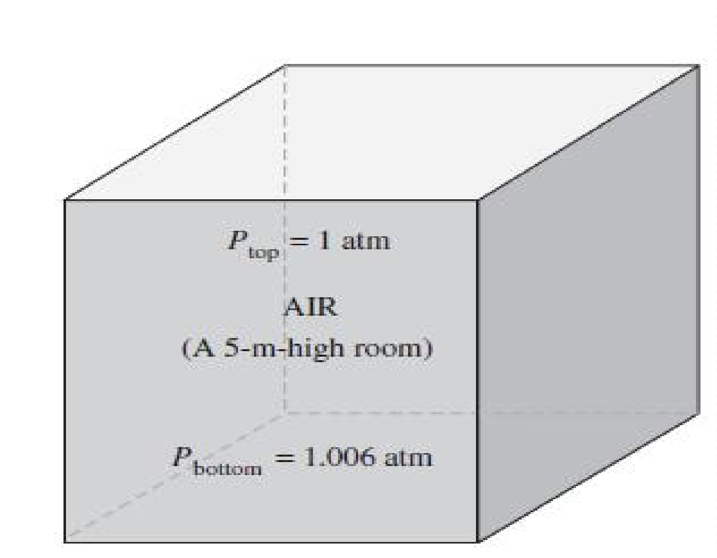


Fig.In a room filled with a gas, the variation of pressure with height is negligible.

Conti.

Pressure in a fluid at rest is independent of the shape or cross section of the container. It changes with the vertical distance, but remains constant in other directions. Therefore, the pressure is the same at all points on a horizontal plane in a given fluid.

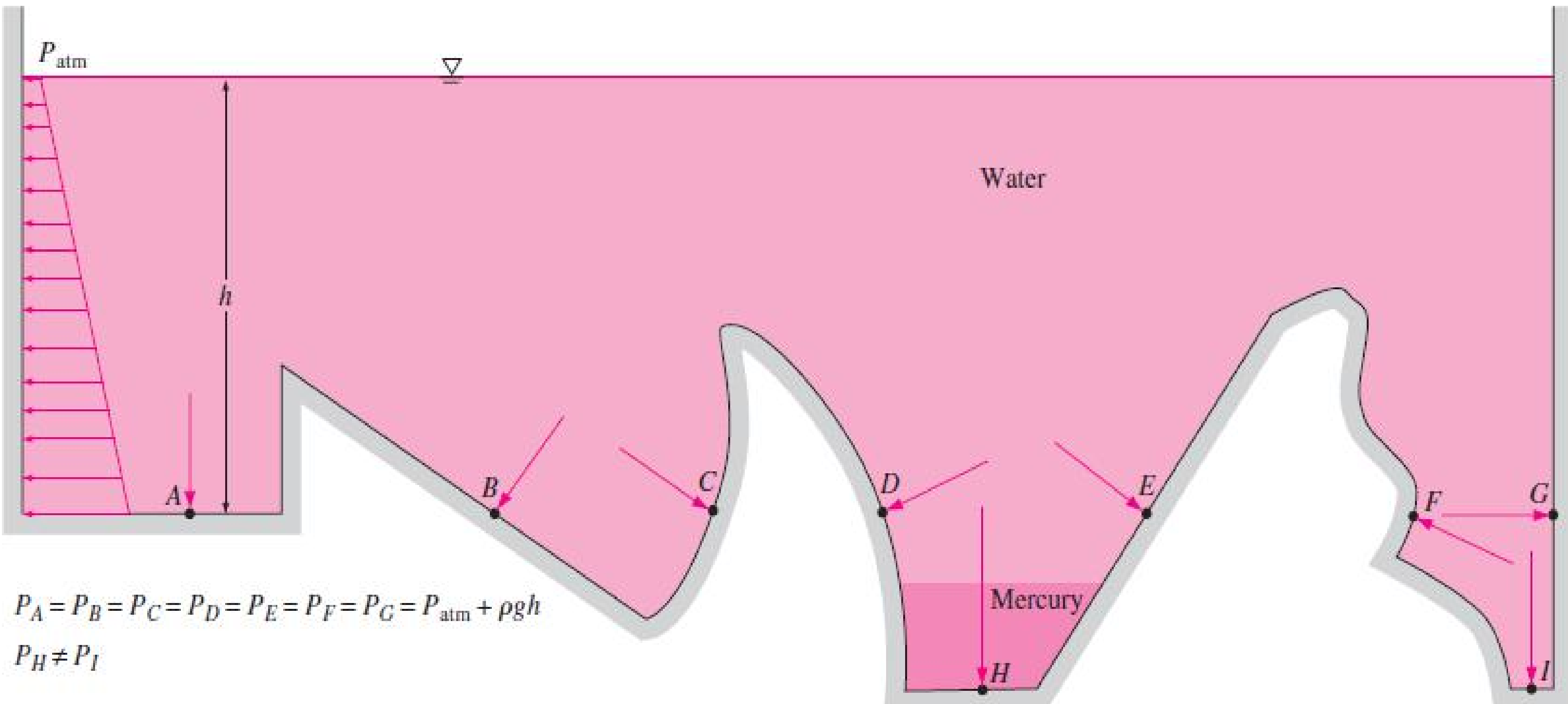


Fig. The pressure is the same at all points on a horizontal plane in a given fluid regardless of geometry, provided that the points are interconnected by the same fluid.

Conti.

Pascal’s law

A consequence of the pressure in a fluid remaining constant in the horizontal direction is that the pressure applied to a confined fluid increases the pressure throughout by the same amount. This is called **Pascal’s law.**

Pascal also knew that the force applied by a fluid is proportional to the surface area. He realized that two hydraulic cylinders of different areas could be connected, and the larger could be used to exert a proportionally greater force than that applied to the smaller. “Pascal’s machine” has been the source of many inventions that are a part of our daily lives such as hydraulic brakes and lifts. This is what enables us to lift a car easily by one arm,as shown in fig.below.

Conti.

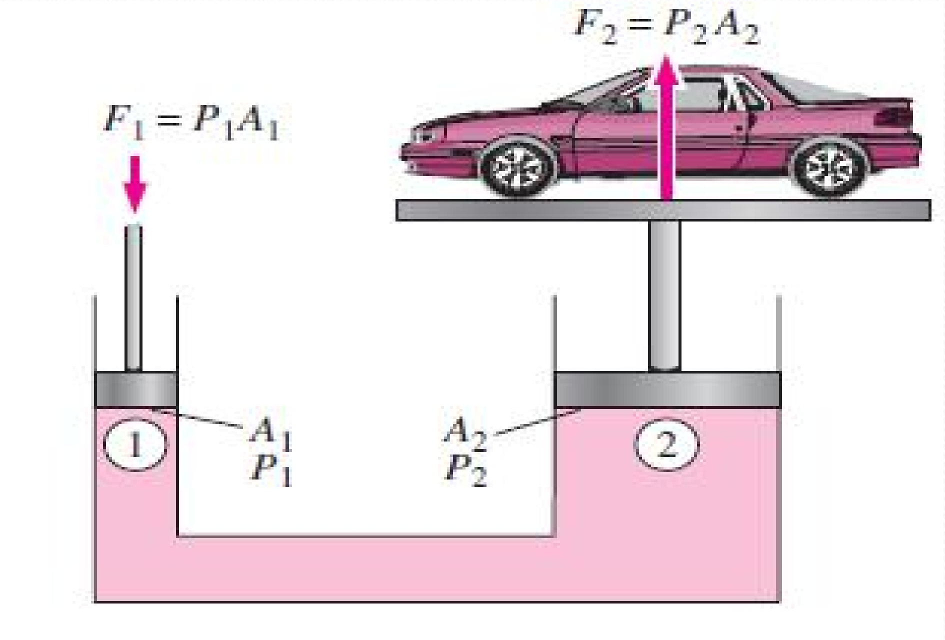


Fig. Lifting of a large weight by a small force by the application of Pascal's law.

$P_1 = P_2$,Since both pistons are at the same level (the effect of small height differences is negligible, especially at high pressures), the ratio of output force to input force is determined to be

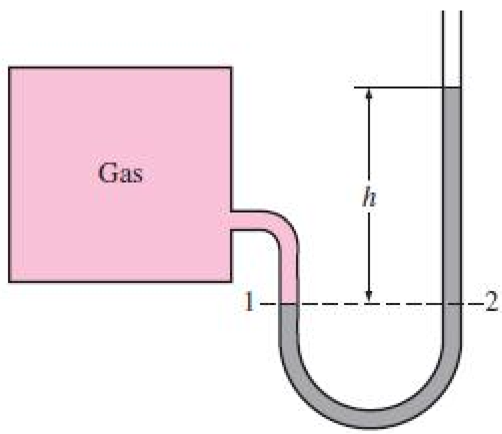
Conti.

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

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 (= 981 N).

Manometer

It is commonly used to measure small and moderate pressure differences. A manometer mainly consists of a glass or plastic U-tube containing one or more fluids such as mercury, water, alcohol, or oil. To keep the size of the manometer to a manageable level, heavy fluids such as mercury are used if large pressure differences are anticipated.



since pressure in a fluid does not vary in the horizontal direction within a fluid, the pressure at point 2 is the same as the pressure at point 1, $P_2 = P_1$

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

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.

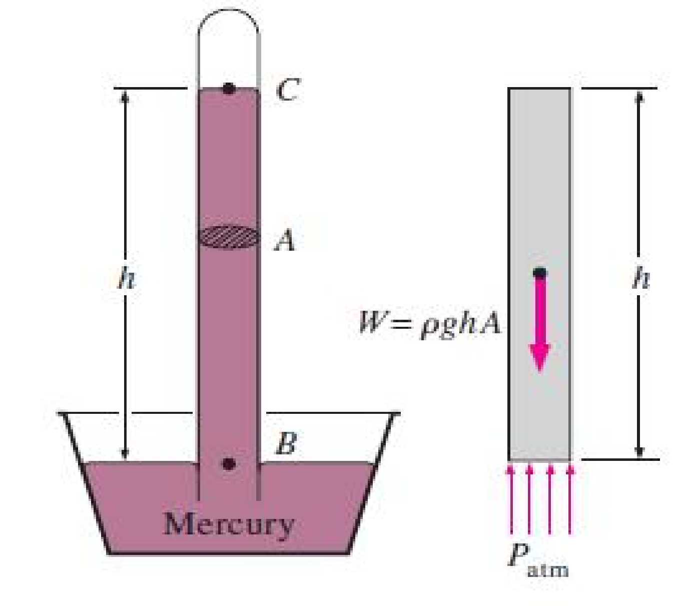


FIG. The basic barometer

CONTI.

The pressure at point B is equal to the atmospheric pressure, and the pressure at C can be taken to be zero since there is only mercury vapor above point C and the pressure is very low relative to P_{atm} and can be neglected to an excellent approximation. Writing a force balance in the vertical direction gives

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

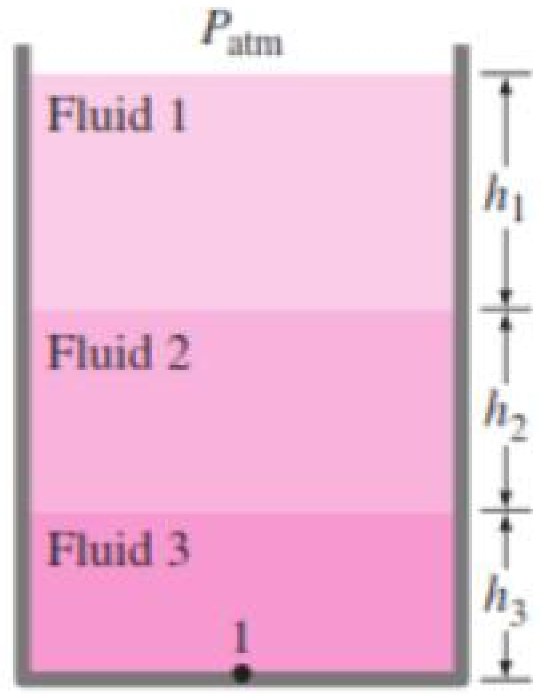
The pressure change across a fluid layer of density

Many engineering problems and some manometers involve multiple immiscible fluids of different densities stacked on top of each other. Such systems can be analyzed easily by remembering that (1) the pressure change across a fluid column of height h is $\Delta P = \rho g h$, (2) pressure increases downward in a given fluid and decreases upward (i.e., $P_{bottom} > P_{top}$), and (3) two points at the same elevation in a continuous fluid at rest are at the same pressure.

The last principle, which is a result of *Pascal's law*, allows us to "jump" from one fluid column to the next in manometers without worrying about pressure change as long as we don't jump over a different fluid, and the fluid is at rest. Then the pressure at any point can be determined by starting with a point of known pressure and adding or subtracting $\rho g h$ terms as we advance toward the point of interest. For example, the pressure at the bottom of the tank in Fig. 1–47 can be determined by starting at the free surface where the pressure is P_{atm}, moving downward until we reach point 1 at the bottom, and setting the result equal to P_1. It gives

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

Cont….

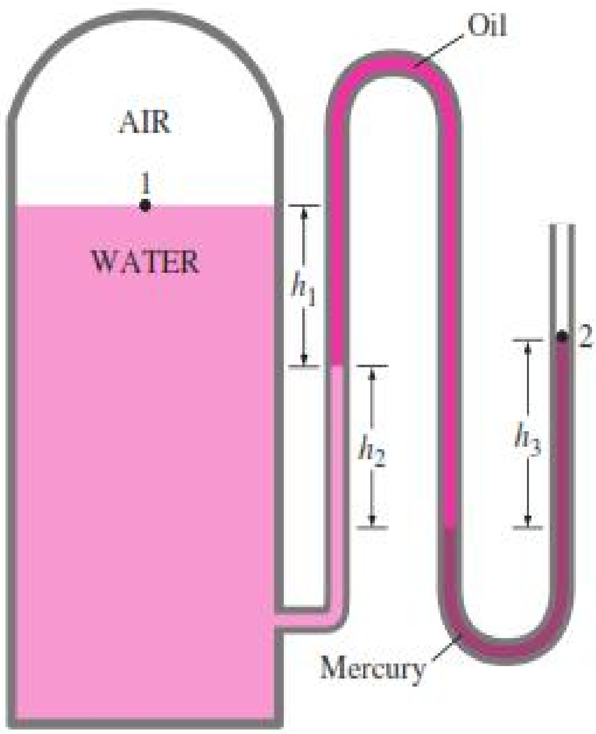


Example one

The water in a tank is pressurized by air, and the pressure is measured by a multifluid manometer as shown in Fig. 1–49. 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 of water, oil, and mercury to be 1000 kg/m^3, 850 kg/m^3, and 13,600 kg/m^3, respectively.

Solution The pressure in a pressurized water tank is measured by a multi-fluid 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.
Properties The densities of water, oil, and mercury are given to be 1000 kg/m^3, 850 kg/m^3, and 13,600 kg/m^3, respectively.
Analysis Starting with the pressure at point 1 at the air–water interface, moving along the tube by adding or subtracting the ρgh terms until we reach point 2, and setting the result equal to P_{atm} since the tube is open to the atmosphere gives

Cont.....



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

Solving for P_1 and substituting,

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

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

$$= 85.6 \text{ kPa} + (9.81 \text{ m/s}^2)[(13{,}600 \text{ kg/m}^3)(0.35\text{m}) - 1000 \text{ kg/m}^3)(0.1 \text{ m})$$

$$-(850 \text{ kg/m}^3)(0.2 \text{ m})]\left(\frac{1 \text{ N}}{1 \text{ kg} \cdot \text{m/s}^2}\right)\left(\frac{1 \text{ kPa}}{1000 \text{ N/m}^2}\right)$$

$$= 130 \text{ kPa}$$