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Thermodynamics

الديناميكا الحرارية

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Thermodynamics الديناميكا الحرارية

CHAPTER ONE Basic Principles

We introduce a thermodynamic system as a control volume, which for a fixed mass is a control mass. Such a system can be isolated, exchanging neither mass, momentum, or energy with its surroundings. A closed system versus an open system refers to the ability of mass exchange with the surroundings. If properties for a substance change, the state changes and a process occurs. When a substance has gone through several processes returning to the same initial state it has completed a cycle.

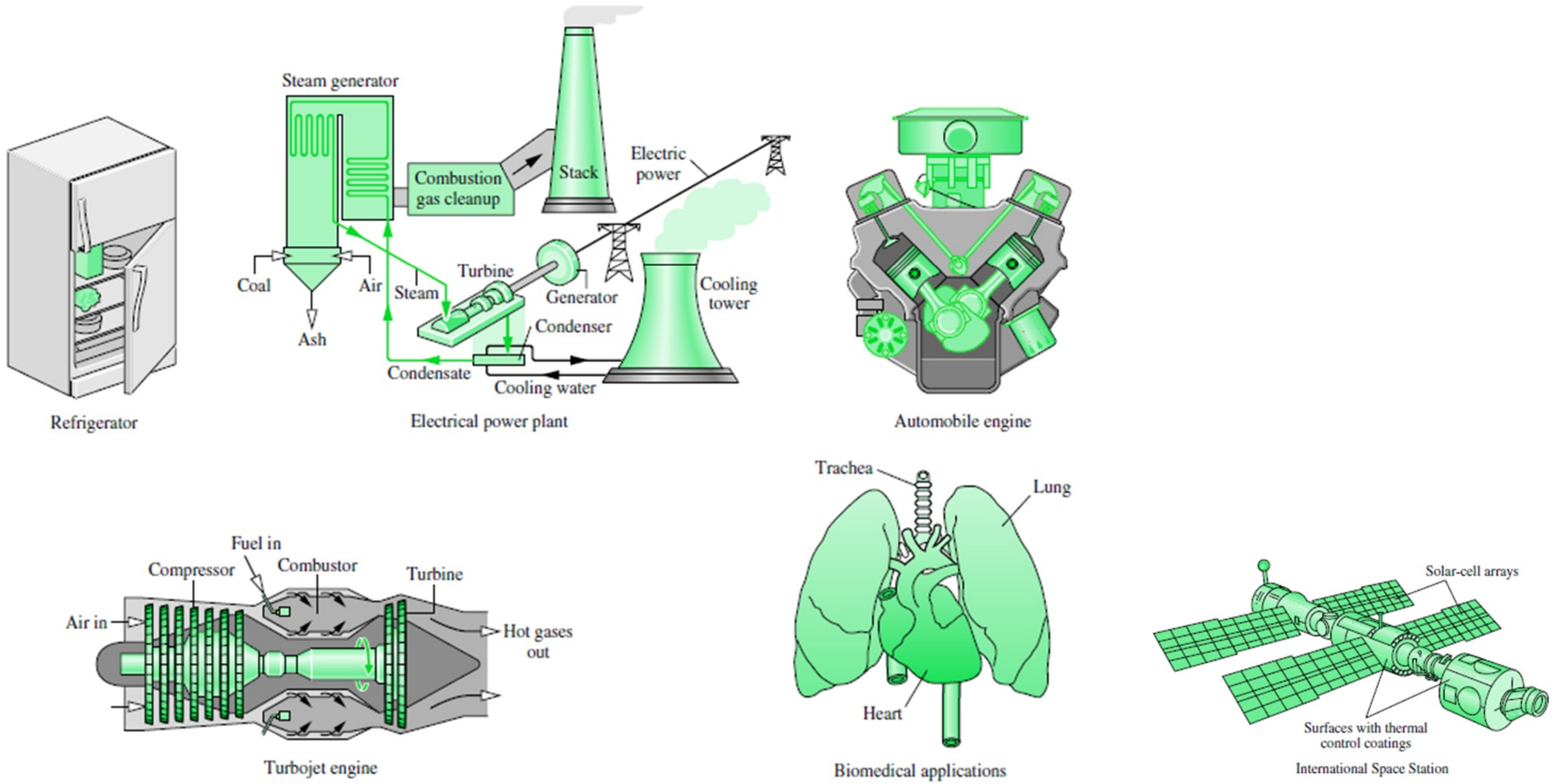
Basic units for thermodynamic and physical properties are mentioned and most are covered in Table A.1. Thermodynamic properties such as density ρ, specific volume v, pressure P, and temperature T are introduced together with units for these. Properties are classified as intensive, independent of mass (like v), or extensive, proportional to mass (like V). Students should already be familiar with other concepts from physics such as force F, velocity **V**, and acceleration a. Application of Newton's law of motion leads to the variation of the static pressure in a column of fluid and the measurements of pressure (absolute and gauge) by barometers and manometers. The normal temperature scale and the absolute temperature scale are introduced.

You should have learned a number of skills and acquired abilities from studying this chapter that will allow you to

- Define (choose) a control volume (C.V.) around some matter; sketch the content and identify storage locations for mass; and identify mass and energy flows crossing the C.V. surface.
- Know properties P, T, v, and ρ and their units.
- Know how to look up conversion of units in Table A.1.
- Know that energy is stored as kinetic, potential, or internal (in molecules).
- Know that energy can be transferred.
- Know the difference between (v, ρ) and (V, m) intensive versus extensive.
- Apply a force balance to a given system and relate it to pressure P.
- Know the difference between a relative (gauge) and absolute pressure P.
- Understand the working of a manometer or a barometer and get ΔP or P from height H.
- Know the difference between a relative and absolute temperature T.
- Have an idea about magnitudes (v, ρ, P, T).

1.1 The System and Control Volume

The *system* is whatever we want to study. It may be as simple as a free body or as complex as an entire chemical refinery. We may want to study a quantity of matter contained within a closed, rigid-walled tank, or we may want to consider something such as a pipeline through which natural gas flows. The composition of the matter inside the system may be fixed or may be changing through chemical or nuclear reactions. The shape or volume of the system being analyzed is not necessarily constant, as when a gas in a cylinder is compressed by a piston or a balloon is inflated.

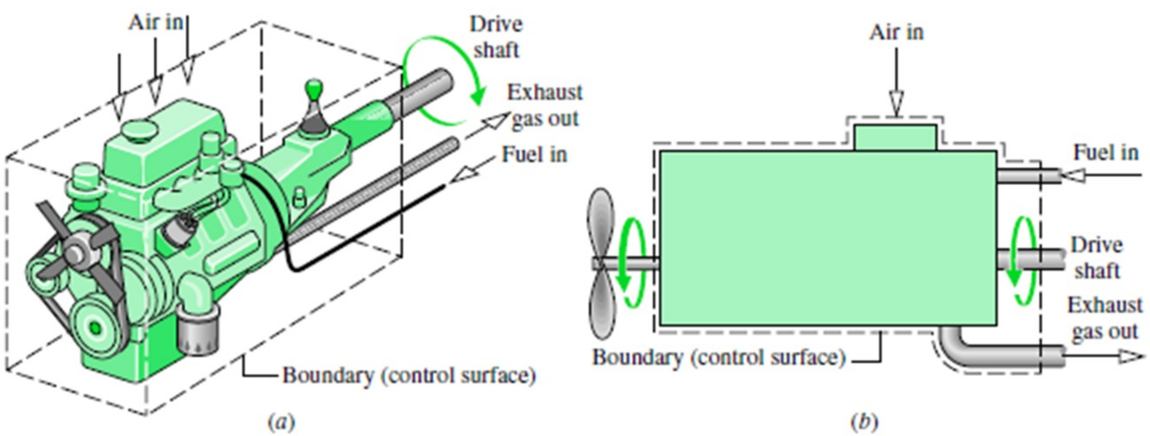


TYPES OF SYSTEMS

Two basic kinds of systems are distinguished in this presentation. These are referred to, respectively, as *closed systems* and *control volumes*. A closed system refers to a fixed quantity of matter, whereas a control volume is a region of space through which mass may flow.

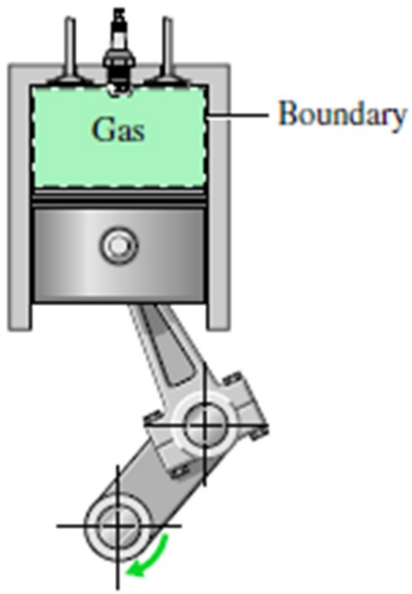
A *closed system* is defined when a particular quantity of matter is under study. A closed system always contains the same matter. There can be no transfer of mass across its boundary.

A special type of closed system that does not interact in any way with its surroundings is called an *isolated system.* Figure 1.1 shows a gas in a piston–cylinder assembly. When the valves are closed, we can consider the gas to be a closed system. The boundary lies just inside the piston and cylinder walls, as shown by the dashed lines on the figure. The portion of the boundary between the gas and the piston moves with the piston. No mass would cross this or any other part of the boundary.



Example of a control volume (open system). An automobile engine.

control volume



1.2 Macroscopic Description

MACROSCOPIC AND MICROSCOPIC VIEWS OF THERMODYNAMICS

Systems can be studied from a macroscopic or a microscopic point of view. The macroscopic approach to thermodynamics is concerned with the gross or overall behavior. This is sometimes called *classical* thermodynamics. No model of the structure of matter at the molecular, atomic, and subatomic levels is directly used in classical thermodynamics.

Although the behavior of systems is affected by molecular structure, classical thermodynamics allows important aspects of system behavior to be evaluated from observations of the overall system.

The microscopic approach to thermodynamics, known as *statistical* thermodynamics, is concerned directly with the structure of matter. The objective of statistical thermodynamics is to characterize by statistical means the average behavior of the particles making up a system of interest and relate this information to the observed macroscopic behavior of the system.

For applications involving lasers, plasmas, high-speed gas flows, chemical kinetics, very low temperatures (cryogenics), and others, the methods of statistical thermodynamics are essential. Moreover, the microscopic approach is instrumental in developing certain data, for example, ideal gas specific heats

1.3 Properties and State of a System

The matter in a system may exist in several phases: a solid, a liquid, or a gas. A *phase* is a quantity of matter that has the same chemical composition throughout; that is, it is *homogeneous*. It is all solid, all liquid, or all gas. Phase boundaries separate the phases in what, when taken as a whole, is called a *mixture.* Gases can be mixed in any ratio to form a single phase. Two liquids that are miscible form a mixture when mixed; but liquids that are not miscible, such as water and oil, form two phases.

A *pure substance* is uniform in chemical composition. It may exist in more than one phase, such as ice, liquid water, and vapor, in which each phase would have the same composition. A uniform mixture of gases is a pure substance as long as it does not react chemically (as in combustion) or liquefy in which case the composition would change.

A *property* is any quantity that serves to describe a system. The *state* of a system is its condition as described by giving values to its properties at a particular instant.

The common properties are pressure, temperature, volume, velocity, and position; others must occasionally be considered. Shape is important when surface effects are significant

Thermodynamic properties are divided into two general types, intensive and extensive. An *intensive property* is one that does not depend on the mass of the system. Temperature, pressure, density, and velocity are examples since they are the same for the entire system, or for parts of the system. If we bring two systems together, intensive properties are not summed.

An *extensive property* is one that does depend on the mass of the system; mass, volume, momentum, and kinetic energy are examples. If two systems are brought together the extensive property of the new system is the sum of the extensive properties of the original two systems.

1.4 Equilibrium, Processes, and Cycles

When the temperature of a system is referred to, it is assumed that all points of the system have the same, or approximately the same, temperature. When the properties are constant from point to point and when there is no tendency for change with time, a condition of *thermodynamic equilibrium* exists. If the temperature, for example, is suddenly increased at some part of the system boundary, spontaneous redistribution is assumed to occur until all parts of the system are at the same increased temperature. If a system would undergo a large change in its properties when subjected to some small disturbance, it is said to be in *metastable equilibrium.* A mixture of gasoline and air, and a bowling ball on top of a pyramid are examples.

When a system changes from one equilibrium state to another, the path of successive states through which the system passes is called a *process.* If, in the passing from one state to the next, the deviation from equilibrium is small, and thus negligible, a *quasiequilibrium* process occurs; in this case, each state in the process can be idealized as an equilibrium state. Quasiequilibrium processes can approximate many processes, such as the compression and expansion of gases in an internal combustion engine, with acceptable accuracy.

If a system undergoes a quasiequilibrium process (such as the compression of air in a cylinder of an engine) it may be sketched on appropriate coordinates by using a solid line, as shown between states 1 and 2 in Fig. 1.4*a.* If the system, however, goes from one equilibrium state to another through a series of nonequilibrium states (as in combustion) a *nonequilibrium process* occurs.

In Fig. 1.4*b* the dashed curve represents a nonequilibrium process between ($V1$, $P1$) and ($V2$, $P2$); properties are not uniform throughout the system and thus the state of the system is not known at each state between the two end states.

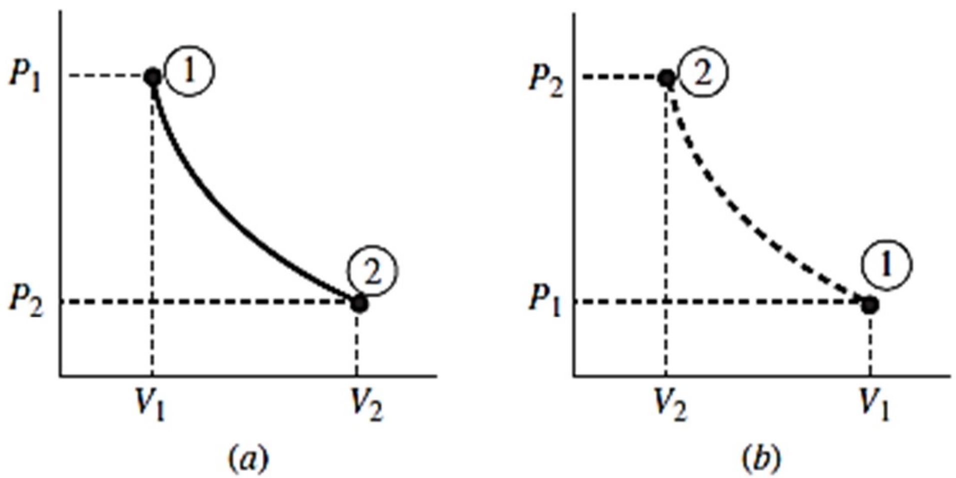


Figure 1.4 A process. (*a*) Quasiequilibrium. (*b*) Nonequilibrium.

When a system in a given initial state experiences a series of quasiequilibrium processes and returns to the initial state, the system undergoes a *cycle.* At the end of the cycle the properties of the system have the same values they had at the beginning.

The prefix *iso-* is attached to the name of any property that remains unchanged in a process. An *isothermal* process is one in which the temperature is held constant; in an *isobaric* process, t he pressure remains constant; an *isometric* process is a constant-volume process. Note the isobaric and the isometric legs in Fig. 1.6 (the lines between states 4 and 1 and between 2 and 3, respectively).

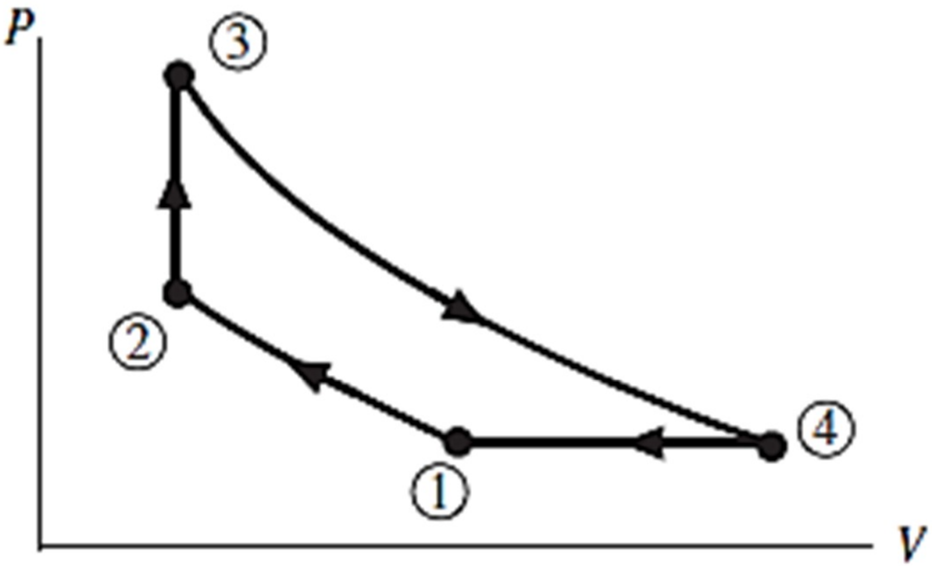


Figure 1.6 Four processes that make up a cycle.

1.5 Units

Quantity	Symbol	SI Units	English Units	To Convert from English to SI Units Multiply by
Length	L	m	ft	0.3048
Mass	m	kg	lbm	0.4536
Time	t	s	sec	1
Area	A	m^2	ft^2	0.09290
Volume	V	m^3	ft^3	0.02832
Velocity	V	m/s	ft/sec	0.3048
Acceleration	a	m/s^2	ft/sec^2	0.3048
Angular velocity	ω	rad/s	rad/sec	1
Force, Weight	F, W	N	lbf	4.448
Density	ρ	kg/m^3	lbm/ft^3	16.02
Specific weight	γ	N/m^3	lbf/ft^3	157.1
Pressure	P	kPa	psi	6.895
Work, Energy	W, E, U	J	ft · lbf	1.356
Heat transfer	Q	J	Btu	1055
Power	$\dot{W}$	W	ft · lbf/sec	1.356
		W	hp	746
Heat flux	$\dot{Q}$	J/s	Btu/sec	1055
Mass flux	$\dot{m}$	kg/s	lbm/sec	0.4536
Flow rate	$\dot{V}$	m^3/s	ft^3/sec	0.02832
Specific heat	C	kJ/kg · K	Btu/lbm · °R	4.187
Specific enthalpy	h	kJ/kg	Btu/lbm	2.326
Specific entropy	s	kJ/kg · K	Btu/lbm · °R	4.187
Specific volume	v	m^3/kg	ft^3/lbm	0.06242

Weight is the force of gravity; by Newton's second law,

$$W = mg$$

Since mass remains constant, the variation of W is due to the change in the acceleration of gravity g (from about 9.77 m/s^2 on the highest mountain to 9.83 m/s^2 in the deepest ocean trench, only about a 0.3% variation from 9.80 m/s^2). We will use the standard sea-level value of 9.81 m/s^2 (32.2 ft/sec^2), unless otherwise stated.

Example

5kg plastic tank that has a volume of $0.2m^3$ is filled with liquid water. Assuming the density of water is $1000kg/m^3$, determine the weight of the combined system.

Solution: given mass of tank m_t=5kg

Volume of the tank $V=0.2m^3$

Density of water $\rho_w=1000kg/m^3$

Mass of water $m_w = V_w x \rho_w$

$=0.2m^3 \times 1000kg/m^3 = 200kg$

total mass $m = m_w + m_t$

$=200kg+5kg$

total weight $w = m \times g = 205kg \times 9.81m/sec^2 = 2011N$

Example

What is the force required to accelerate a mass of 30kg at a rate of $15m/sec^2$.

Solution: given , mass $m=30kg$

Acceleration $a = 15m/sec^2$

$F= m \times a = 30kg \times 15m/sec^2 = 450N$

Since it is frequently necessary to work with extremely large or small values when using the SI unit system, a set of standard prefixes is provided in Table below to simplify matters. For example, km denotes kilometer, that is, 10^3m.

Factor	Prefix	Symbol
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	h
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

Quantity	Units	Symbol	Name
Velocity	m/s		
Acceleration	m/s^2		
Force	kg m/s^2	N	newtons
Pressure	kg m/s^2 (N/m^2)	Pa	pascal
Energy	kg m^2/s^2 (N m)	J	joule
Power	kg m^2/s^3 (J/s)	W	watt

1.6 Density, Specific Volume, and Specific Weight

$$density = \frac{mass}{volume} = \frac{kg}{m^3} \quad ; \rho = \frac{m}{V}$$

specific volume *v* is volume per unit mass. By comparing their definitions, we see that the two properties are related by

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

Associated with (mass) density is *weight density*, or *specific weight* Υ :

$$\Upsilon = \frac{W}{V} \qquad \text{with units } N/m^3$$

(Note that Υ is volume-specific, not mass-specific.) Specific weight is related to density through $W = mg$:

$$\gamma = \frac{mg}{mv} = \rho g$$

For water, nominal values of ρ and Υ are, respectively, 1000 kg/m^3 and 9810 N/m^3. For air at standard conditions, the nominal values are 1.21 kg/m^3 and 11.86 N/m^3.

Example 1 The mass of air in a room 3 m × 5 m × 20 m is known to be 350 kg. Determine the density, specific volume, and specific weight of the air.

Solution

$$\rho = \frac{m}{V} = \frac{350}{3 \times 5 \times 20} = 1.167 \text{ kg/m}^3$$

$$v = \frac{1}{\rho} = \frac{1}{1.167} = 0.857 \text{ m}^3/\text{kg}$$

$$\gamma = \rho g = 1.167 \times 9.81 = 11.45 \text{ N/m}^3$$

1.7 Pressure

In gases and liquids, the effect of a normal force acting on an area is the *pressure.* If a force ΔF acts at an angle to an area ΔA (Fig. 1.7), only the normal component ΔF_n enters into the definition of *pressure*:

$$P = \lim_{\Delta A \to 0} \frac{\Delta F_n}{\Delta A}$$

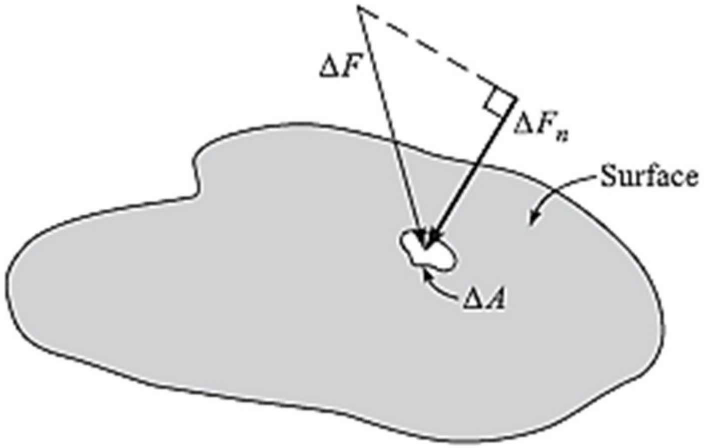


Figure 1.7 The normal component of a force.

The SI unit of pressure and stress is the pascal.
1 pascal =1 N/m^2

However, in this text it is convenient to work with multiples of the pascal: the kPa, the bar, and the MPa.

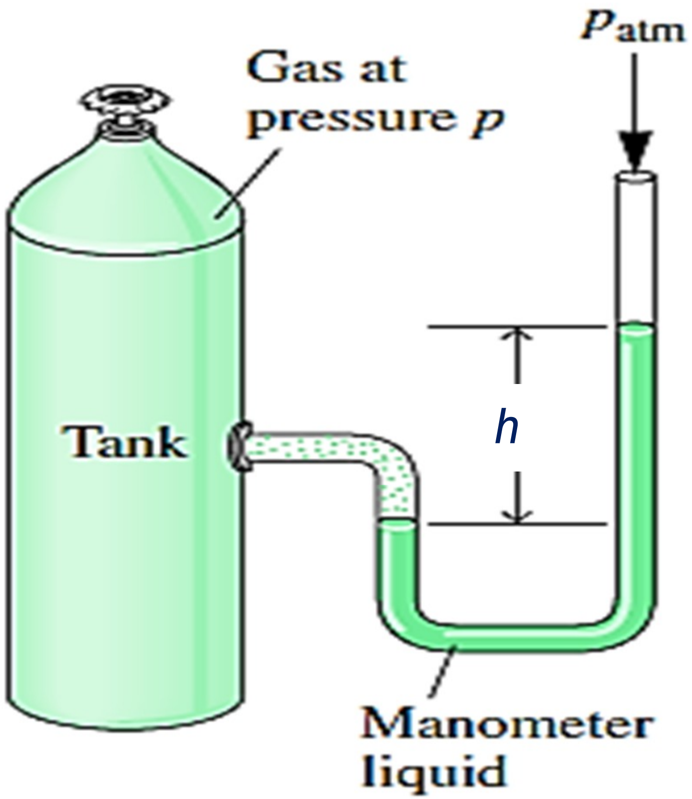
$$1 \text{ kPa} = 10^3 \text{ N/m}^2$$
$$1 \text{ bar} = 10^5 \text{ N/m}^2$$
$$1 \text{ MPa} = 10^6 \text{ N/m}^2$$

Although atmospheric pressure varies with location on the earth, a standard reference value can be defined and used to express other pressures.

$$1 \text{ standard atmosphere (atm)} = 1.01325 \times 10^5 \text{ N/m}^2$$

PRESSURE VARIATION WITH ELEVATION

$$p = p_{atm} + \rho g h$$



In many relations, *absolute pressure* must be used. Absolute pressure is gage pressure plus the local atmospheric pressure:

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

$$P_{abs} = P_{atm} - P_{gage(vacuum)}$$

A negative gage pressure is often called a *vacuum,* and gages capable of reading negative pressures are *vacuum gages.* A gage pressure o f –50 kPa would be referred to as a vacuum of 50 kPa (the sign is omitted). Figure 1.8 shows the relationships between absolute and gage pressure at two different points.

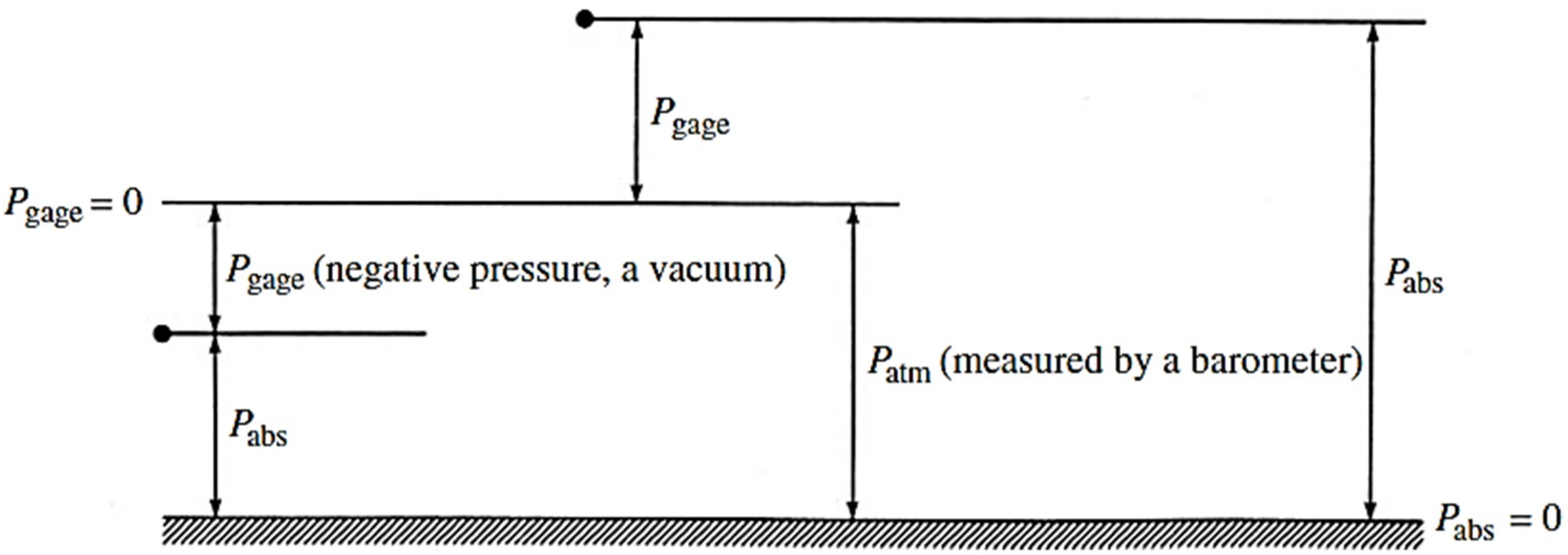
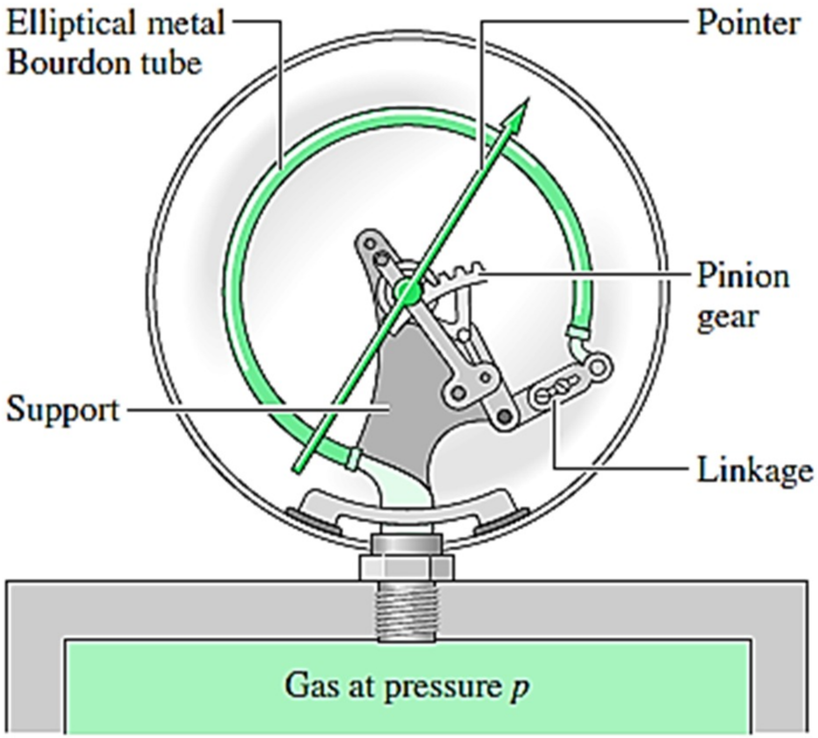
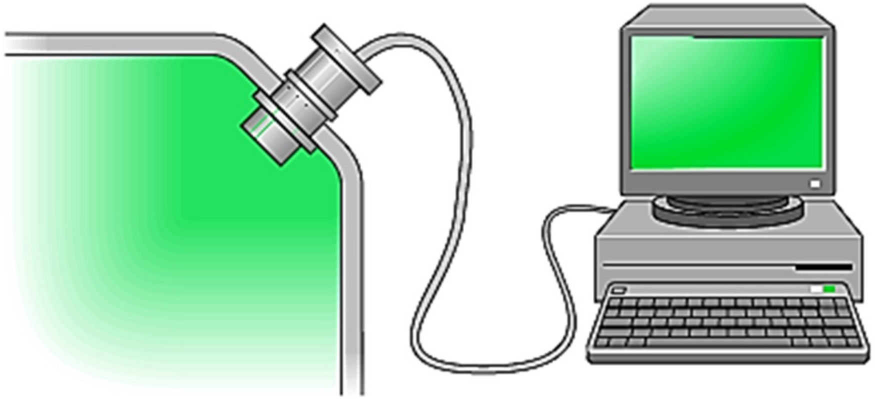


Figure 1.8 Absolute and gage pressure.



Pressure measurement by a Bourdon tube gage.



Pressure sensor with automatic data acquisition.

Table B.1 The U.S. Standard Atmosphere

Altitude, m	Temperature, °C	Pressure, P/P_0	Density, ρ/ρ_0
0	15.2	1.000	1.000
1 000	9.7	0.8870	0.9075
2 000	2.2	0.7846	0.8217
3 000	–4.3	0.6920	0.7423
4 000	–10.8	0.6085	0.6689
5 000	–17.3	0.5334	0.6012
6 000	–23.8	0.4660	0.5389
7 000	–30.3	0.4057	0.4817
8 000	–36.8	0.3519	0.4292
10 000	–49.7	0.2615	0.3376
12 000	–56.3	0.1915	0.2546
14 000	–56.3	0.1399	0.1860
16 000	–56.3	0.1022	0.1359
18 000	–56.3	0.07466	0.09930
20 000	–56.3	0.05457	0.07258
30 000	–46.5	0.01181	0.01503

$P_0 = 101.3$ kPa, $\rho_0 = 1.225$ kg/m^3

EXAMPLE

Express a pressure gage reading of 20 mm Hg in absolute pascals at an elevation of 2000 m. Use $\gamma_{Hg} = 13.6\gamma_{water}$.

Solution

First we convert the pressure reading into pascals. We have

$$P = \gamma_{Hg} h = (13.6 \times 9810)\ \frac{N}{m^3} \times 0.020\ m = 2668\ \frac{N}{m^2} \quad \text{or} \quad 2668\ Pa$$

To find the absolute pressure we simply add the atmospheric pressure to the above value. Referring to Table B.1, $P_{atm} = 0.7846 \times 101.3 = 79.48$ kPa. The absolute pressure is then

$$P = P_{gage} + P_{atm} = 2.668 + 79.48 = 82.15\ kPa$$

1.8 Temperature

Temperature is actually a measure of molecular activity

EQUALITY OF TEMPERATURES

Let two bodies be isolated from the surroundings but placed in contact with each other. If one is hotter than the other, the hotter body will become cooler and the cooler body will become hotter; both bodies will undergo change until all properties (e.g., pressure) of the bodies cease to change. When this occurs, *thermal equilibrium*

A rather obvious observation is referred to as the *zeroth law of thermodynamics:*

if two systems are equal in temperature to a third, they are equal i n temperature to each other.

<u>TEMPERATURE SCALE:</u>

Celcsius scale symbol ^oC or called Centigrade. The Celsius scale was based on two fixed, easily duplicated points, the ice point and the steam point, these two points are numbered 0^oC and 100^oC on the Celsius scale. And absolute scale related to Celsius is referred to as the Kelvin scale and is designated as K.

$K = {}^oC + 273.15$

There is other scale of temperature called Fahrenheit scale has symbol ^oF at which the ice point and steam point are numbered 32^oF and 212^oF.

$$0^oC \rightarrow 32^oF$$

$$100^oC \rightarrow 212^oF$$

$$T(^oF) = 32 + 1.8T(^oC)$$

And the absolute scale related to Fahrenheit scale is referred as the Rankin and designated R

$$R = {}^{o}F + 460$$
$$T(R) = 1.8T(K)$$

<u>Example</u>

Consider a system whose temperature is 18°C. Express this temperature in R, K, and °F.

Solution: given t=18°C

T(°F)=32+1.8T(°C)

=32+1.8 x 18=64.4°F

T(K)=T(°C)+273

=18+273.15=291.15K

T(R) =T(°F)+459.67

=64.4+459.67=524.07R

or T(R)=1.8T(K)=1.8 x 291.15=524.07R

<u>Example</u>

The deep body temperature of a healthy person is 37°C. What is it in Kelvin.

Solution: given T(c)=37°C

T(k)=T(c)+273.15=310.15K

1.9 Energy

Kinetic Energy: it is the energy that a system possesses as a result of its motion relative to some reference frame, when all parts of a system move with the same velocity, the kinetic energy is expressed as

$$KE = \frac{1}{2} mC^2 \quad [J]$$

Or, on a unit mass basis,

$$ke = \frac{1}{2} C^2 \quad [J/kg]$$

And the change in kinetic energy between two state of the system

$$\Delta KE = \frac{1}{2}(m_2 C_2^2 - m_1 C_1^2) \quad [J]$$

or

$$\Delta KE = \frac{1}{2000}(m_2 C_2^2 - m_1 C_1^2) \quad [kJ]$$

And for the same mass m

$$\Delta KE = \frac{1}{2000} m(C_2^2 - C_1^2) \quad [kJ]$$

Where C denotes the velocity of the system relative to some fixed reference frame.

Potential Energy : It is the energy that a system possesses as a result of its elevation in a gravitational- field and is expressed as

$$PE = mgZ \qquad [J]$$

Or, on a unit mass basis

$$pe = gZ \qquad [J/kg]$$

and the change in the potential energy is

$$\Delta PE = mg(Z_2 - Z_1) \qquad [J]$$

or

$$\Delta PE = \frac{1}{1000} mg(Z_2 - Z_1) \qquad [kJ]$$

The total energy of a system consists of the kinetic, potential, and internal energies and is expressed as

$$E = U + KE + PE \qquad \text{kJ}$$

or per unit mass

$$e = u + ke + pe \qquad \text{kJ/kg}$$

The sum of all the microscopic forms of energy is called the internal energy of a system and is denoted by U.

Consider a system composed of two automobiles that hit head on and are at rest after the collision. Because the energy of the system is the same before and after the collision, the initial total kinetic energy *KE* must simply have been transformed into another kind of energy, in this case, internal energy *U*, stored primarily in the deformed metal.

EXAMPLE

A 2200-kg automobile traveling at 90 km/h (25 m/s) hits the rear of a stationary, 1000-kg automobile. After the collision the large automobile slows to 50 km/h (13.89 m/s), and the smaller vehicle has a speed of 88 km/h (24.44 m/s). What has been the increase in internal energy, taking both vehicles as the system?

Solution

The kinetic energy before the collision is ($V = 25$ m/s)

$$KE_1 = \frac{1}{2} m_a V_a^2 = \frac{1}{2} \times 2200 \times 25^2 = 687\,500 \text{ J}$$

where the subscript a refers to the first automobile; the subscript b refers to the second one. After the collision the kinetic energy is

$$KE_2 = \frac{1}{2} m_a V_a^2 + \frac{1}{2} m_b V_b^2 = \frac{1}{2} \times 2200 \times 13.89^2 + \frac{1}{2} \times 1000 \times 24.44^2 = 510\,900 \text{ J}$$

The conservation of energy requires that

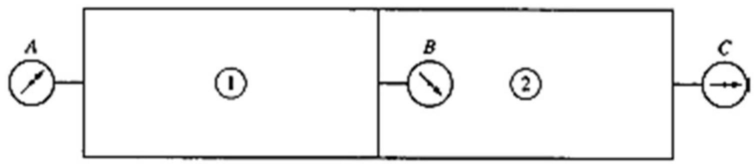
$$E_1 = E_2 \qquad \text{or} \qquad KE_1 + U_1 = KE_2 + U_2$$

Thus,

$$U_2 - U_1 = KE_1 - KE_2 = 687\,500 - 510\,900 = 176\,600 \text{ J} \quad \text{or} \quad 176.6 \text{ kJ}$$

Quiz No. 1

1. Engineering thermodynamics does not include energy
   - (A) transfer
   - (B) utilization
   - (C) storage
   - (D) transformation
2. Which of the following would be identified as a control volume?
   - (A) Compression of the air-fuel mixture in a cylinder
   - (B) Filling a tire with air at a service station
   - (C) Compression of the gases in a cylinder
   - (D) The flight of a dirigible
3. Which of the following is a quasiequilibrium process?
   - (A) Mixing a fluid
   - (B) Combustion
   - (C) Compression of the air-fuel mixture in a cylinder
   - (D) A balloon bursting
4. The standard atmosphere in meters of gasoline ($\gamma = 6660$ N/m^3) is nearest
   - (A) 24.9 m
   - (B) 21.2 m
   - (C) 18.3 m
   - (D) 15.2 m
5. A gage pressure of 400 kPa acting on a 4-cm-diameter piston is resisted by a spring with a spring constant of 800 N/m. How much is the spring compressed? Neglect the piston weight and friction.
   - (A) 63 cm
   - (B) 95 cm
   - (C) 1.32 m
   - (D) 1.98 m
6. Which of the following processes can be approximated by a quasiequilibrium process?
   - (A) The expansion of combustion gases in the cylinder of an automobile engine
   - (B) The rupturing of a balloon
   - (C) The heating of the air in a room with a radiant heater
   - (D) The cooling of a hot copper block brought into contact with ice cubes
7. Determine the weight of a mass at a location where $g = 9.77$ m/s^2 (on the top of Mt. Everest) if it weighed 40 N at sea level.
   - (A) 39.62 N
   - (B) 39.64 N
   - (C) 39.78 N
   - (D) 39.84 N
8. Determine γ if $g = 9.81$ m/s^2, $V = 10$ m^3, and $v = 20$ m^3/kg.
   - (A) 2.04 N/m^3
   - (B) 1.02 N/m^3
   - (C) 0.49 N/m^3
   - (D) 0.05 N/m^3
9. If $P_{atm} = 100$ kPa, the pressure at a point where the gage pressure is 300 mmHg is nearest ($\gamma_{Hg} = 13.6\,\gamma_{water}$)
   - (A) 40 kPa
   - (B) 140 kPa
   - (C) 160 kPa
   - (D) 190 kPa
10. A large chamber is separated into compartments 1 and 2, as shown, that are kept at different pressures. Pressure gage A reads 400 kPa and pressure gage B reads 180 kPa. If the barometer reads 720 mmHg, determine the absolute pressure of C.



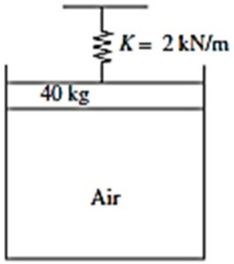
   - (A) 320 kPa
   - (B) 300 kPa
   - (C) 280 kPa
   - (D) 260 kPa

Quiz No. 2

11. A 10-kg body falls from rest, with negligible interaction with its surroundings (no friction). Determine its velocity after it falls 5 m.
    - (A) 19.8 m/s
    - (B) 15.2 m/s
    - (C) 12.8 m/s
    - (D) 9.9 m/s
12. The potential energy stored in a spring is given by $Kx^2/2$, where K is the spring constant and x is the distance the spring is compressed. Two springs are designed to absorb the kinetic energy of an 1800-kg vehicle. Determine the spring constant necessary if the maximum compression is to be 100 mm for a vehicle speed of 16 m/s.
    - (A) 23 MN/m
    - (B) 25 MN/m
    - (C) 27 MN/m
    - (D) 29 MN/m

1. In a quasiequilibrium process, the pressure
    - (A) remains constant
    - (B) varies with location
    - (C) is everywhere constant at an instant
    - (D) depends only on temperature
2. Which of the following is not an extensive property?
    - (A) Momentum
    - (B) Internal energy
    - (C) Temperature
    - (D) Volume
3. The joule unit can be converted to which of the following?
    - (A) $kg \cdot m^2/s$
    - (B) $kg \cdot m/s^2$
    - (C) $Pa \cdot m^3$
    - (D) Pa/m^2

4. Convert 178 kPa gage of pressure to absolute millimeters of mercury ($\rho_{hg} = 13.6\rho_{water}$).
   (A) 2080 mm
   (B) 1820 mm
   (C) 1640 mm
   (D) 1490 mm
5. Calculate the pressure in the 240-mm-diameter cylinder shown. The spring is compressed 60 cm. Neglect friction.



   (A) 198 kPa
   (B) 135 kPa
   (C) 110 kPa
   (D) 35 kPa
6. A cubic meter of a liquid has a weight of 9800 N at a location where $g = 9.79$ m/s^2. What is its weight at a location where $g = 9.83$ m/s^2?
   (A) 9780 N
   (B) 9800 N
   (C) 9820 N
   (D) 9840 N
7. Calculate the force necessary to accelerate a 900-kg rocket vertically upward at the rate of 30 m/s^2.
   (A) 18.2 kN
   (B) 22.6 kN
   (C) 27.6 kN
   (D) 35.8 kN
8. Calculate the weight of a body that occupies 200 m^3 if its specific volume is 10 m^3/kg.
   (A) 20 N
   (B) 92.1 N
   (C) 132 N
   (D) 196 N
9. The pressure at a point where the gage pressure is 70 cm of water is nearest
   (A) 169 kPa
   (B) 107 kPa
   (C) 69 kPa
   (D) 6.9 kPa
10. A bell jar 200 mm in diameter sits on a flat plate and is evacuated until a vacuum of 720 mmHg exists. The local barometer reads 760 mmHg. Estimate the force required to lift the jar off the plate. Neglect the weight of the jar.
   (A) 3500 N
   (B) 3000 N
   (C) 2500 N
   (D) 2000 N
11. An object that weighs 4 N traveling at 60 m/s enters a viscous liquid and is essentially brought to rest before it strikes the bottom. What is the increase in internal energy, taking the object and the liquid as the system? Neglect the potential energy change.
   (A) 734 J
   (B) 782 J
   (C) 823 J
   (D) 876 J
12. A 1700-kg vehicle traveling at 82 km/h collides head-on with a 1400-kg vehicle traveling at 90 km/h. If they come to rest immediately after impact, determine the increase in internal energy, taking both vehicles as the system.
   (A) 655 kJ
   (B) 753 kJ
   (C) 879 kJ
   (D) 932 kJ