THERMODYNAMICS

INTRODUCTION

The word thermodynamics is derived from two Greek words
Therm which means **heat**
Dynamis which means **power**

Together the spell *heat power* which fits the time when the forefathers of thermodynamics set out to convert heat to power.

In this day and age we define thermodynamics as the *"science of energy"* where thermodynamics covers all aspect of energy and energy transformation.

The First Law of Thermodynamics

The first law of thermodynamics is basically the conservation of energy principle which states that *energy can change from one form to another but energy cannot be created or destroyed*.

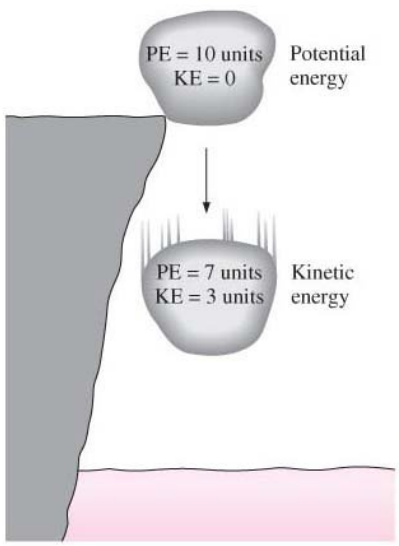
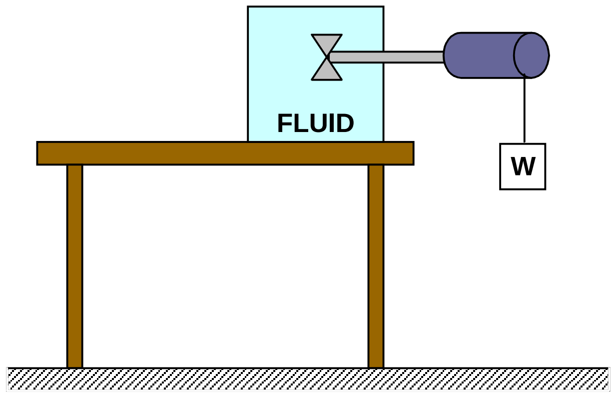


FIGURE 1–1
Energy cannot be created or destroyed; it can only change forms (the first law).

The Second Law of Thermodynamics

The second law of thermodynamics states that the quality of this energy is degraded irreversibly.



Potential energy of the weight, W is converted to heat energy in the fluid as the weight drops to the ground. The same heat energy will not cause the weight to move up to its original position. Hence the potential energy has degraded.

Application of Thermodynamics

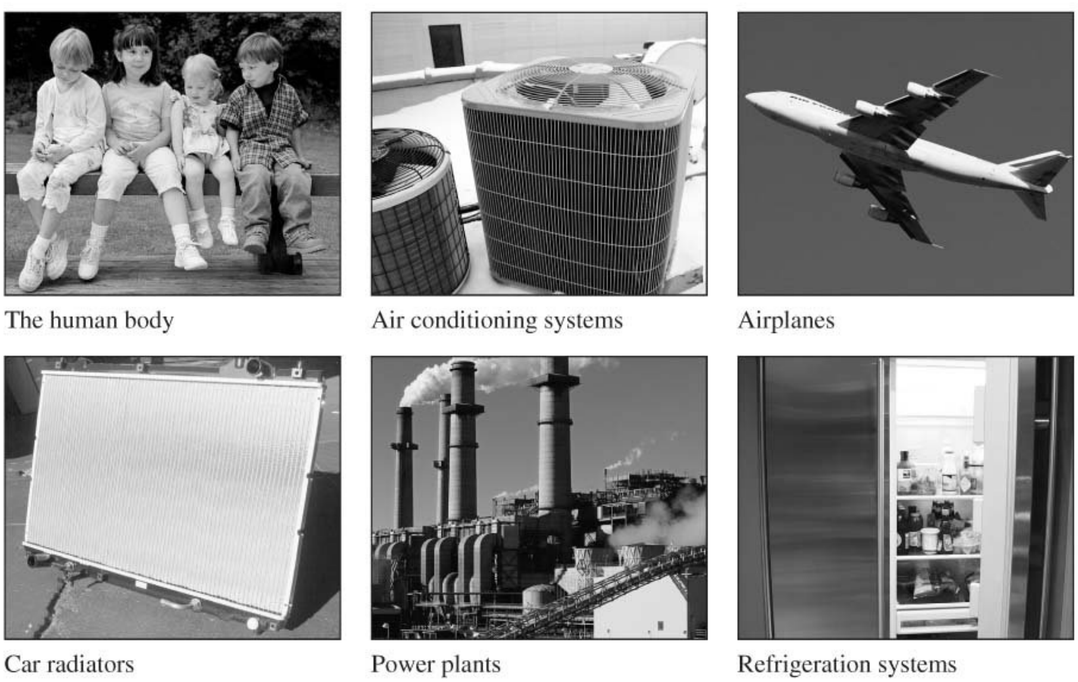


FIGURE 1–5

Some application areas of thermodynamics.

Dimensions and Units

Dimensions are physical quantities such as mass, length and temperature (**primary dimensions**). **Secondary dimensions** include energy, velocity and volume which are derived from primary dimensions.

Units are divided into English system and the SI system. Four fundamental dimensions in thermodynamics are

Length (m)
Mass (kg)
Time (s)
Temperature (K)

Units are always written in small letters except when it was derived from someone's' name like.

Sir Isaac *Newton* (N)
Lord *Kelvin* (William Thomson) (K)
James *Watt* (W)
James Prescott *Joule* (J)

When written out in full, it is not capitalized.

5 newtons
273 kelvins
50 joules

Writing the units in full can be plural but not when it is abbreviated

5 meters	5 m
2 seconds	2 s
5 newtons	5 N

Prefixes are as below

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

Dimensional Homogenity

When solving problems or equations, make sure the right hand side and left hand side have the same units.

Closed and Open System

Thermodynamic System (System)

A system is a quantity of matter or region in space chosen for study.

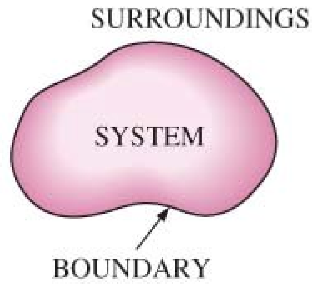


FIGURE 1–15

System, surroundings, and boundary.

Whatever mass or region that is outside a system is called the **surroundings**. The real or imaginary surface that separates the system is called the **boundary**.

A system can be considered to be closed or open system

Closed System

In a closed system energy can cross the boundary of the system but mass cannot.

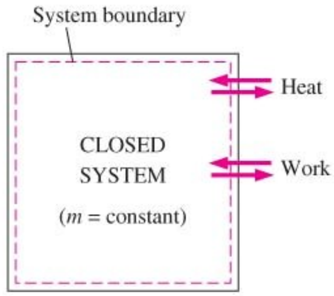


FIGURE 2–11

Energy can cross the boundaries of a closed system in the form of heat and work.

Chapter 1 | 11

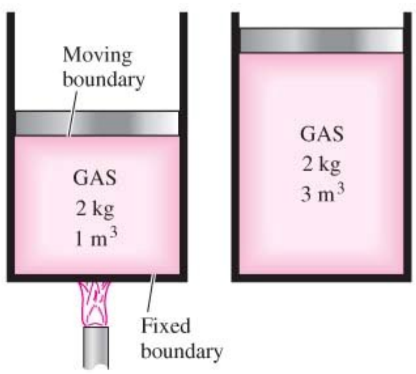
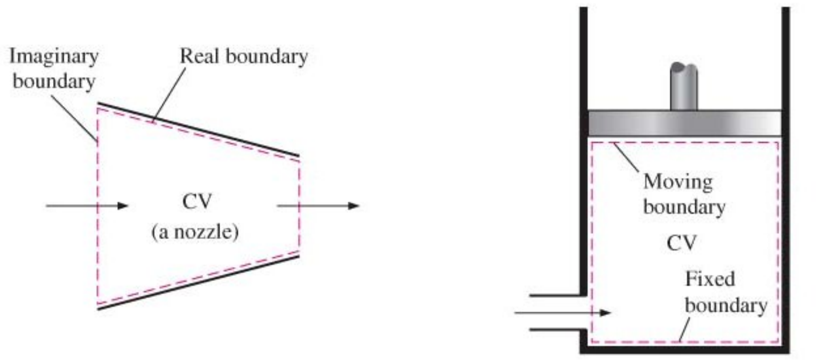


FIGURE 1–17

A closed system with a moving boundary.

Open System or Control Volume
In a control volume, mass and energy can cross the boundary of the system.



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

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

FIGURE 1–18
A control volume can involve fixed, moving, real, and imaginary boundaries.

Thermodynamics analysis for open systems and closed systems are different. Therefore you must be able to recognize which kind of system it is.

Forms of Energy
Energy comes in many forms, kinetic, potential, mechanical, electric, chemical, thermal, nuclear and magnetic but the sum of energy of a system, called the **total energy** is denoted by E and has units of Joule (J).

On a unit mass basis

$$e = \frac{E}{m} \qquad \text{(J/kg)}$$

The total energy of a system can be divided into two groups, **macroscopic** and **microscopic**. Macroscopic energy includes **kinetic energy** denoted KE and, **potential energy** denoted PE. Microscopic energy deals with molecular activity of the system. All forms of microscopic energy are collectively called **internal energy** denoted by U.

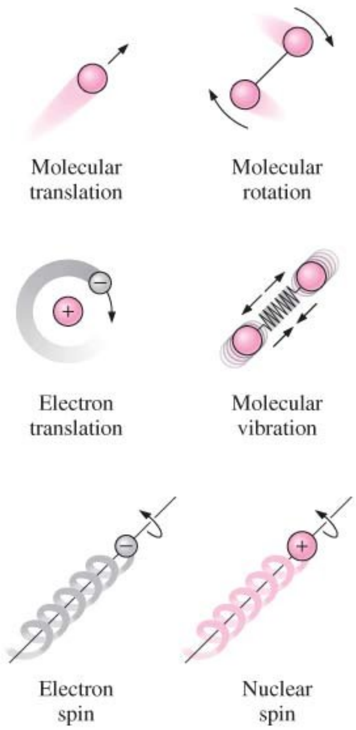


FIGURE 2–5

The various forms of microscopic energies that make up *sensible* energy.

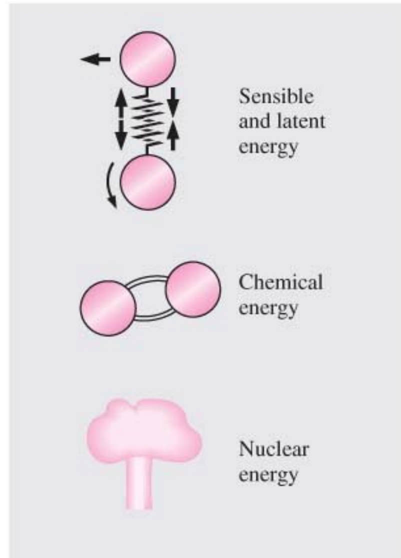


FIGURE 2–6

The internal energy of a system is the sum of all forms of the microscopic energies.

Kinetic energy is expressed as

$$KE = \frac{1}{2} mV^2$$

or on a unit mass basis

$$ke = \frac{1}{2} V^2$$

Potential energy is expressed as

$$PE = mgz$$

or on a unit mass basis

$$pe = gz$$

In the absence of magnetic, electrical energy and other forms of energy we will not be considering. The total energy of a system is given by

$$E = U + KE + PE$$

$$E = U + \frac{1}{2} mV^2 + mgz$$

Or on a unit mass basis

$$e = u + \frac{1}{2} V^2 + gz$$

Properties of a System
Any properties of a system like temperature, pressure volume, mass, etc. are properties of a system. They describe the system. Properties can be classified as **intensive** or **extensive**.

Intensive properties are those that are independent of the size of the system. Example: pressure, temperature and density. Extensive properties are dependent on the size of the system like mass, volume and energy.

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

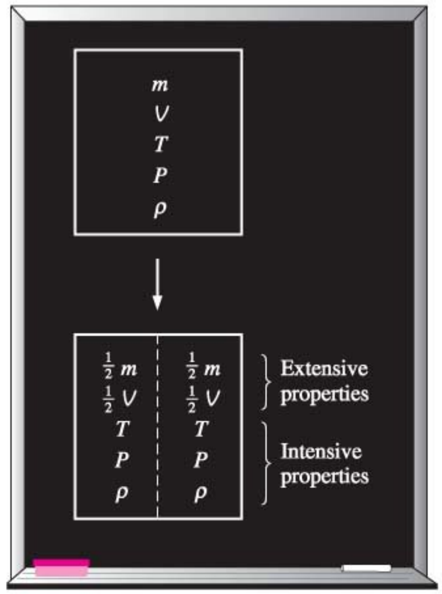


FIGURE 1–20
Criterion to differentiate intensive and extensive properties.

State and Equilibrium
Imagine a system undergoing a change. At this point, all the properties of the system can be measure or calculated throughout the entire system, which gives a set of properties that completely describe the condition or **state** of the system.

Thermodynamics deals with equilibrium states. A system in equilibrium experiences no change when it is isolate from its surroundings. A system is in **thermal equilibrium** when the temperature is the same throughout the system. When a system is in **mechanical equilibrium**, the pressure at any point in the system does not change with time. When a system has two phases, it is in **phase equilibrium** when the mass of the phases does not change with time. A system is in **chemical equilibrium** when the chemical composition of the system does not change with time i.e. no chemical reaction is taking place. Together a system is in **thermodynamic equilibrium**.

Process and Cycles

Any change a system undergoes from one state to another is called a process and a series of states a system passes through is called **path**. To describe a process completely one should specify the initial and final states of the process, the path it follows and the interactions with its surrounding.

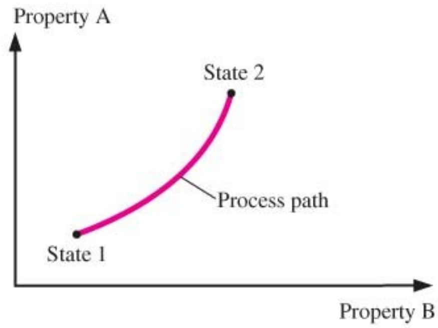


FIGURE 1–26

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

A process undergoes a **cycle** if it returns to its original state at the end of the process.

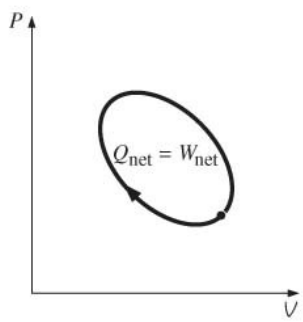


FIGURE 2–46

For a cycle $\Delta E = 0$, thus $Q = W$.

Quasi-equilibrium / Quasi-static

A quasi-equilibrium or quasi-static process is where the process can be viewed as a very slow process that allows the system to adjust itself internally so that properties through out the system is all the same. It is equilibrium at all times. It is an ideal process which does not occur in actual processes.

There are two reasons why engineers are interested in quasi static processes

1) they are easier to analyse
2) they serve as a standard to which actual processes can be compared to actual processes can be compared to.

Iso-processes
Isothermal – constant temperature process
Isobaric – constant pressure process
Isochoric – constant volume process

Pressure
Pressure is expressed as

$$\Pr essure = \frac{Force}{Area}$$

The term pressure can only be sued for gases and liquids. In solids the term stress is used. Pressure of a fluid increased with depth due to weight of the fluid. Pressure is denoted P and has the units N/m^2 or just pascal (Pa).

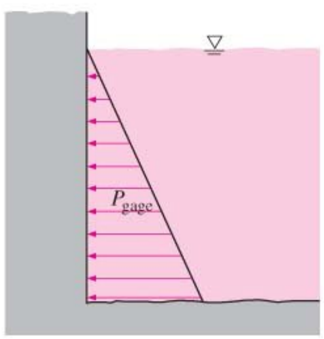


FIGURE 1–39
The pressure of a fluid at rest increases with depth (as a result of added weight).

Actual pressure measured relative to **absolute zero** or **absolute vacuum** is called **absolute pressure**. However devices that measure pressure (pressure gauges) are calibrated to read zero at atmospheric pressure. This is called gage pressure. Any pressure that is below **atmospheric pressure** is called vacuum pressure.

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

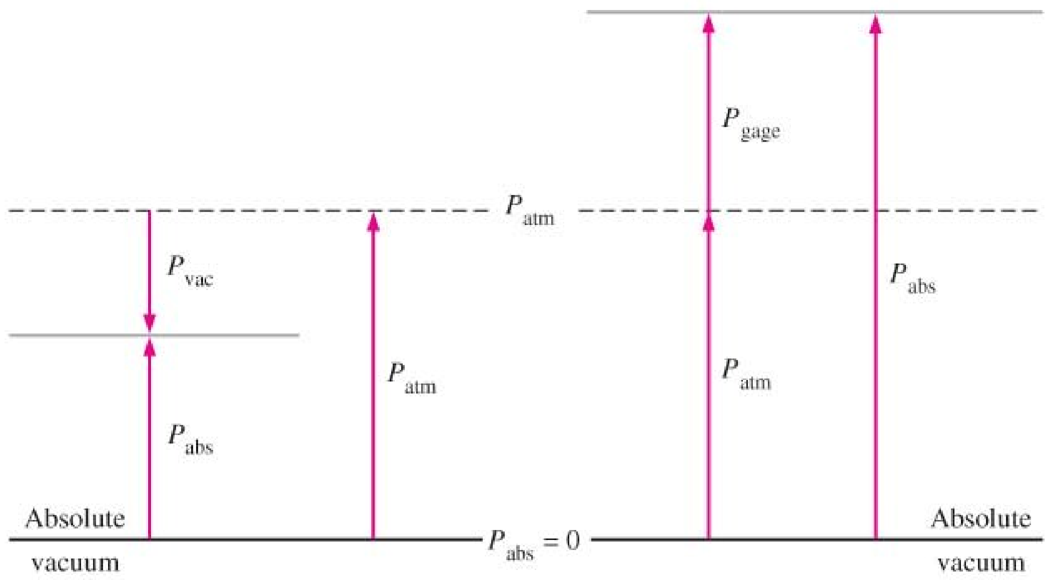


FIGURE 1–38

Absolute, gage, and vacuum pressures.

FIGURE 1–37

Some basic pressure gages.

Dresser Instruments, Dresser, Inc. Used by permission.

Manometer

A manometer is a pressure measuring device which consists of a glass or plastic u-tube. Fluids in the tube can be mercury, water, alcohol or oil. Pressure at point 1 and 2 are the same

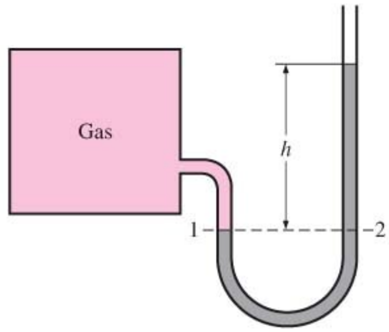


FIGURE 1–45

The basic manometer.

Drawing the FBD of the column height, h gives:

$$+\sum F_y$$

$$AP_1 = AP_{atm} + W$$

$$= AP_{atm} + mg$$

$$= AP_{atm} + \rho Vg$$

$$= AP_{atm} + \rho Ahg$$

$$P_1 = P_{atm} + \rho hg$$

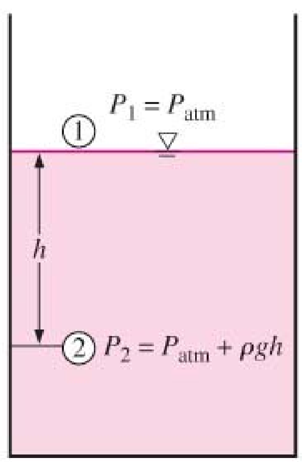


FIGURE 1–42

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

Barometer

The barometer is used to measure atmospheric pressure by inverting a mercury filled tube into a container. Pressure at point B is atmospheric pressure and pressure at point C is zero.

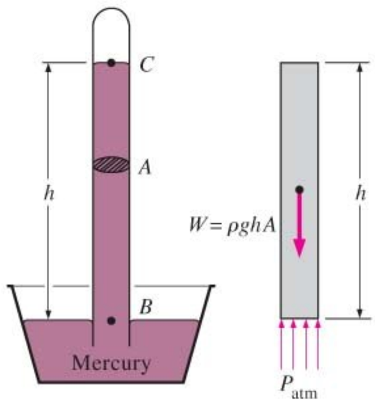


FIGURE 1–51

The basic barometer.

Drawing the FBD of the column height, h gives:

$$+\sum F_y = 0$$
$$AP_{atm} = W$$
$$AP_{atm} = mg$$
$$AP_{atm} = \rho V g$$
$$AP_{atm} = \rho A h g$$
$$P_{atm} = \rho h g$$

The length or cross-sectional area has no effect on the height of the column.

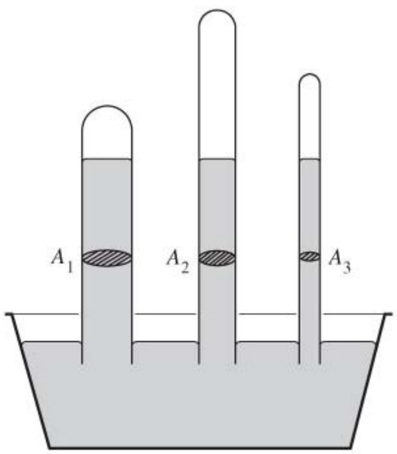


FIGURE 1–52

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.

Pressure can also be written

760 mmHg at 10°C (atmospheric pressure)

Where ρ_{Hg} = 13595 kg/m^3

Other units for pressure are

1 bar = 10^5 Pa = 100 kPa

Atmospheric pressure:

1 atm =101.325 kPa = 1.01325 bars

Density

Density can be expressed

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

Density can also be expressed relative to a well known substance. Then it is called **specific gravity** or **relative density**. Usually, the well known substance for liquids is water at 4°C having density of 1000 kg/m^3.

Specific gravity, $S.G = \frac{\rho}{\rho_{H_2 0}}$

Temperature and the Zeroth Law of Thermodynamics

The zeroth law of thermodynamics state that if two bodies are in thermal equilibrium, with a third body, they are also in thermal equilibrium with each other.

Temperature scales

There are a number of temperature scales

Celcius scale (°C)

Kelvin scale (K)

Rankine scale (R)

Fahrenheit scale (°F)

There are related as such

$$T(K) = T(°\text{C}) + 273.15$$

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

$$T(R) = 1.8T(K)$$

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

But when dealing with temperature difference

$$\Delta T(K) = \Delta T(°\text{C})$$

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