THERMODYNAMICS

Department of Mining Engineering

University of Mosul

SECOND YEAR
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Reference book: Thermodynamics: An Engineering Approach, by
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Chapter One

Introduction and Basic Concepts

1-1- THERMODYNAMICS DEFINITION AND APPLICATIONS

Thermodynamics is the science that deals with the conversion of thermal energy into another form of energy. For example, converting thermal energy into mechanical energy, such as in an internal combustion engine and steam engine, or converting heat energy into electrical energy, as in power stations.

The design of many engineering systems, such as this solar hot water system, involves thermodynamics (Figure 1-1).

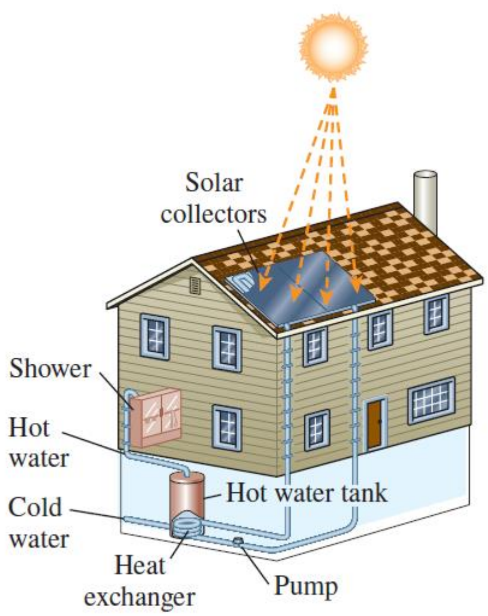


Figure 1-1: Solar collector system.

Thermodynamics plays a major part in 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, these applications are listed in figure 1-2.

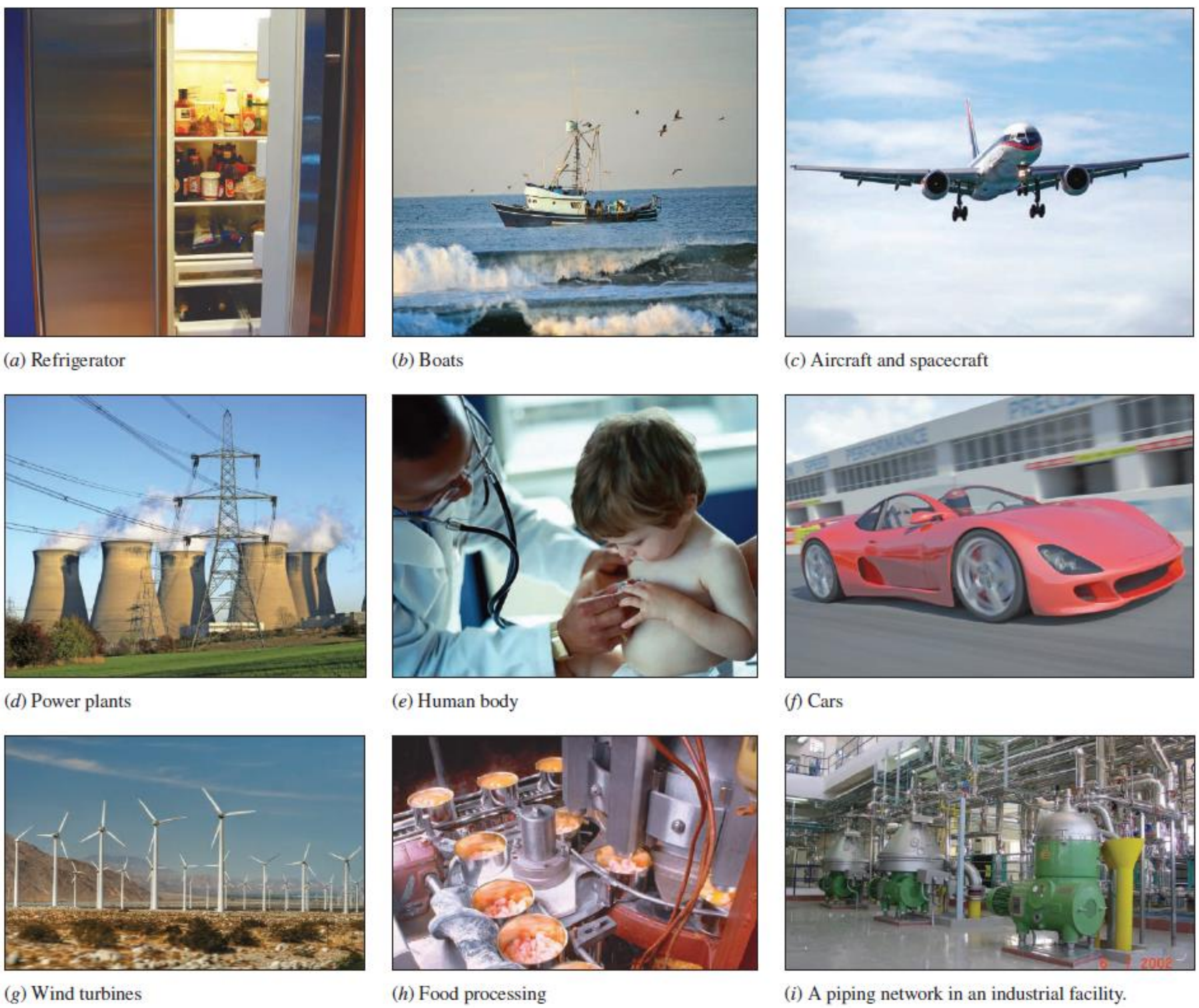


Figure 1-2: Some application areas of thermodynamics.

1-2- IMPORTANCE OF DIMENTIONS 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**. The below figure (Figure 1-3) shows the primary dimensions and their units.

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)

Figure 1-3: The primary dimensions and their units.

In physics, a **force, (F)** is an effect that can change the motion of an object.

Force = (Mass) (Acceleration)

or $F = m\,a$

The force unit is the newton (N), and it is defined as the force required to accelerate a mass of 1 kg at a rate of 1 m/s^2. The below figure (Figure 1-4) represents the definition of force units.

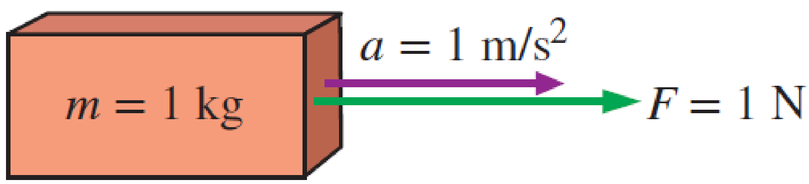


Figure 1-4: The definition of the force units.

Work, (W), which is a form of energy, can simply be defined as force times distance.

Therefore, it has the unit "newton-meter (N.m)," which is called a **joule (J)**. That is,

1 J=1 N.m

Energy, (E), represents the ability of the system to do a work.

Joule (J) is the unit of Energy.

In physics, **power** is the amount of energy transferred or converted per unit time. That is,

$$Power = \frac{Energy}{Time}$$

Therefore, it has the unit "joule (J) per time (s)" which is called a **Watt (W)**.

1-3- SYSTEMS AND CONTROL VOLUMES

A **system** is defined as a quantity of matter or a region in space chosen for study. The mass or region outside the system is called the **surroundings**. The real or imaginary surface that separates the system from its surroundings is called the **boundary**. The below figure (Figure 1-5) represents the system with its surroundings and boundary.

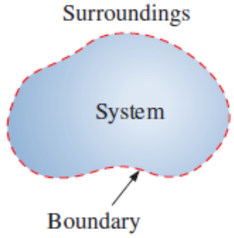


Figure 1-5: System, surroundings, and boundary.

Systems may be considered to be *closed* or *open*, 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 Figure 1–6.

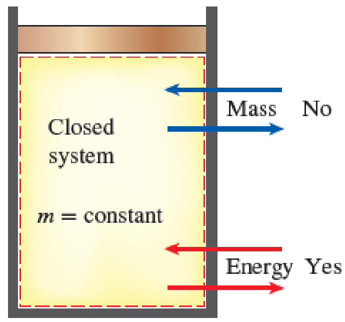


Figure 1-6: Closed system.

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**.

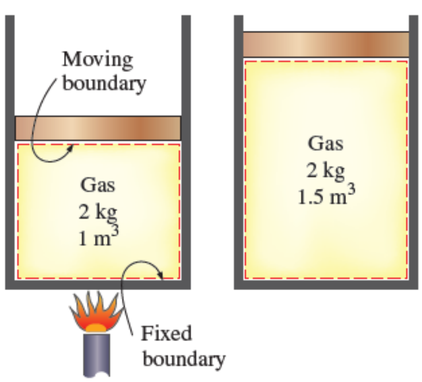
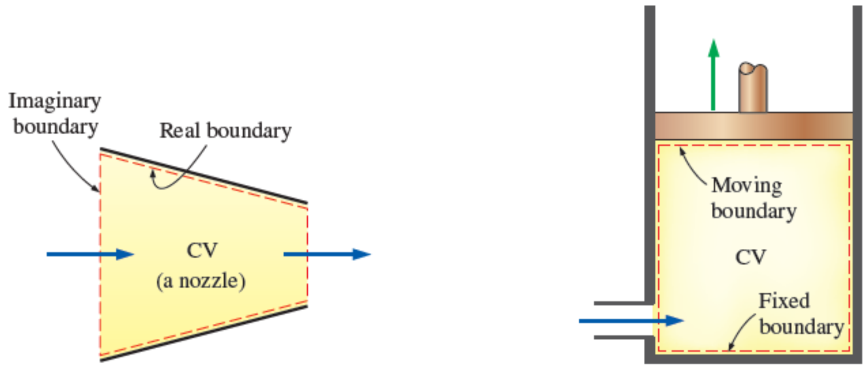


Figure 1-7: A closed system with a moving boundary.

An **open system**, or a **control volume**, involves mass flow such as a compressor, turbine, or nozzle. Figure 1-8 gives examples of open system.



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

(*b*) A control volume (CV) with fixed and moving boundaries as well as real and imaginary boundaries

Figure 1-8: Open system.

1-4- PROPERTIES OF SYSTEM

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 of the system. Total mass, total volume, and total momentum are some examples of extensive properties. Figure 1-9 states both types of properties.

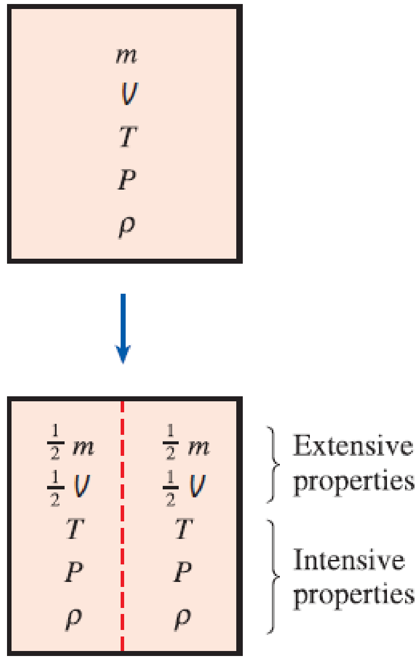


Figure 1-9: Intensive and extensive properties.

1-5- DENSITY AND SPECIFIC GRAVITY

Density is defined as mass per unit volume

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

Specific volume, which is defined as volume per unit mass. That is,

$$\bar{V} = \frac{V}{m} = \frac{1}{\rho} \quad (m^3/kg)$$

Specific gravity, (S.G) or **relative density**, and is defined as the ratio of the density of a substance to the density of water. This is,

$$SG = \frac{\rho}{\rho_{water}}$$

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

Figure 1-10: Specific gravity of some substances.

1-6- STATE AND EQUILIBIRIUM

At a given state, all the properties of a system have fixed values.

Figure 1-11 shows a system is shown at two different states.

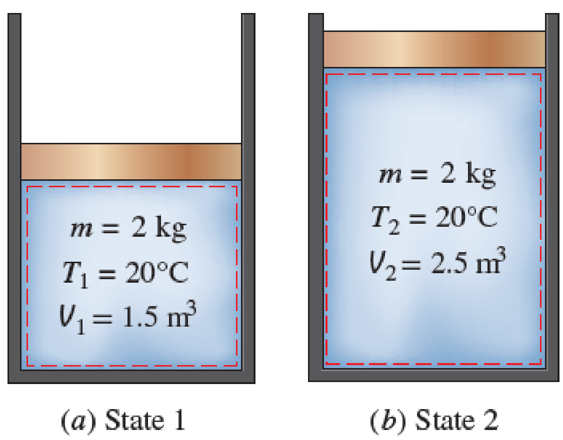


Figure 1-11: A system at two different states.

Thermal equilibrium if the temperature is the same throughout the entire system, as shown in Figure 1-12.

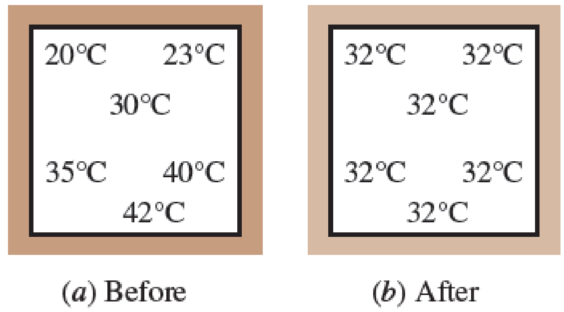


Figure 1-12: A closed system reaching thermal equilibrium.

1-7- PROCESSES AND CYCLES

Any change that a system undergoes from one equilibrium state to another is called a **process**, and the series of states through which a system passes during a process is called the **path** of the process (See: Figure 1–13).

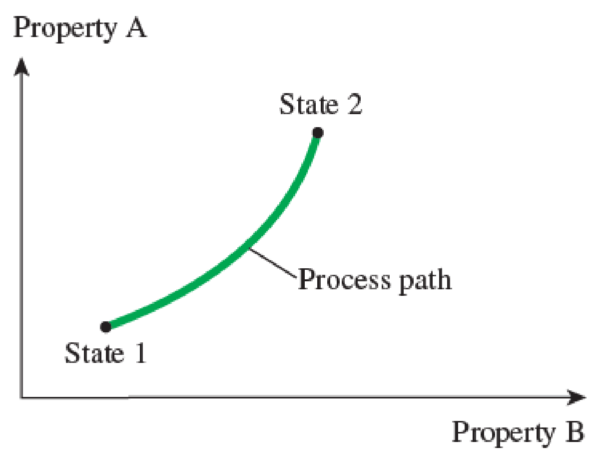


Figure 1-13: A process between states 1 and 2 and the process path.

Figure 1–14 shows the *P-V* diagram of a compression process of a gas.

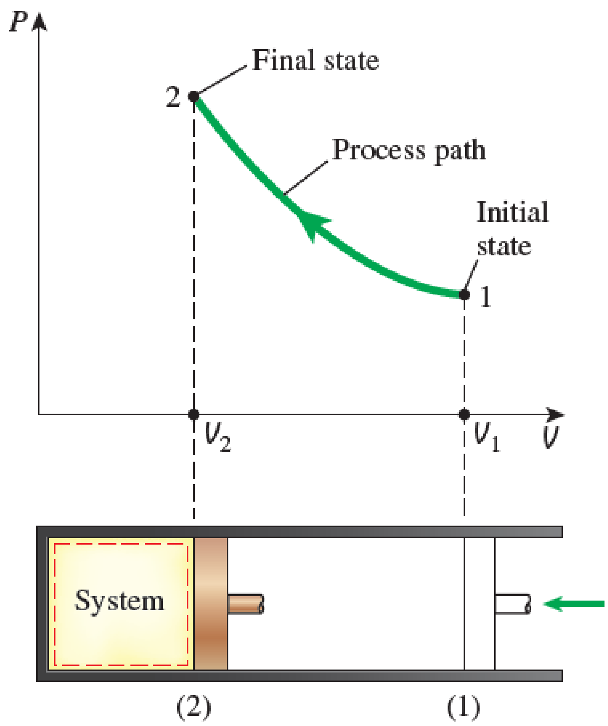


Figure 1-14: The *P-V* diagram of a compression process.

The prefix *iso-* is often used to designate a process for which remains constant. An **isothermal process**, for example, is a process during which the temperature, *T* remains constant; an **isobaric process** is a process during which the pressure, *P* remains constant; and an **isometric process** is a process during which the specific volume, *V* remains constant.

A system is said to have undergone a **cycle** if it returns to its initial state at the end of the process.

During a steady-flow process, fluid properties within the control volume may change with position but not with time. Figure 1-15 shows steady-flow system.

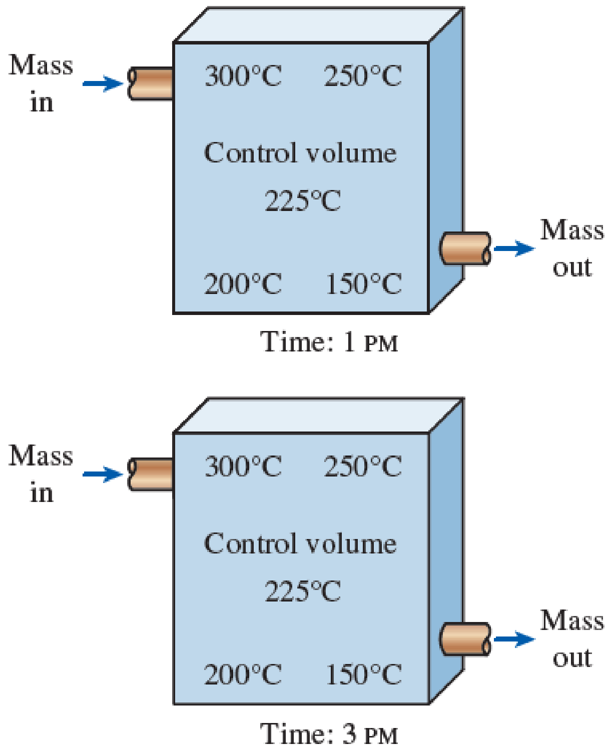


Figure 1-15: A steady-flow system.

1-8- <u>TEMPERATURE AND ZEROTH LAW OF THERMODYNAMICS</u>

The **<u>zeroth law of thermodynamics</u>** states that if two bodies are in thermal equilibrium with a third body, they are also in thermal equilibrium with each other. It may seem silly that such an obvious fact is called one of the basic laws. Below figure shows example to this law.

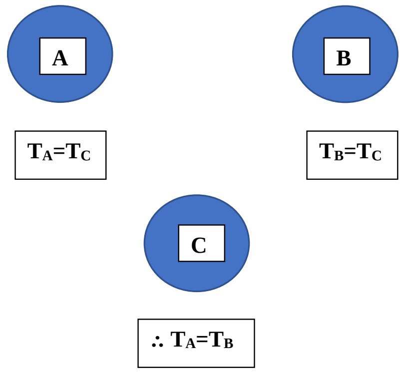


Figure 1-16: Example of zeroth law of thermodynamics.

The temperature in Kelvin scale is related to the Celsius scale given by

$$T\ (K) = T(°C) + 273$$

The temperature in Rankine scale is related to the Fahrenheit scale given by

$$T\ (R) = T(°F) + 460$$

The temperature scales in the two-unit systems are related by

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

$$T\ (°F) = 1.8T(°C) + 32$$

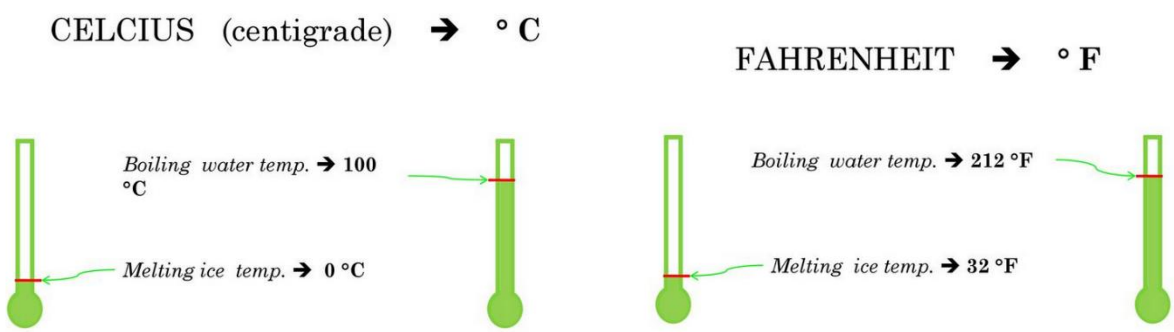


Figure 1-17: Boiling and Melting temperature scales in Celcius and Fahrenheit .

1-9- PRESSURE

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

$$P = \frac{Force}{Area} = \frac{F}{A}$$

Since pressure is defined as force per unit area, it has the unit of newtons per square meter (N/m2), which is called a **pascal, (Pa)**. That is,

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

The pressure unit pascal is too small for most pressures encountered practice. Other pressure units commonly used in practice, especially in Europe, are *bar, standard atmosphere:*

$$1 \text{ bar} = 10^5 \text{ Pa}$$

$$1 \text{ atm} = 101{,}325 \text{ Pa}$$

Absolute, gage, and vacuum pressures are related to each other by:

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

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

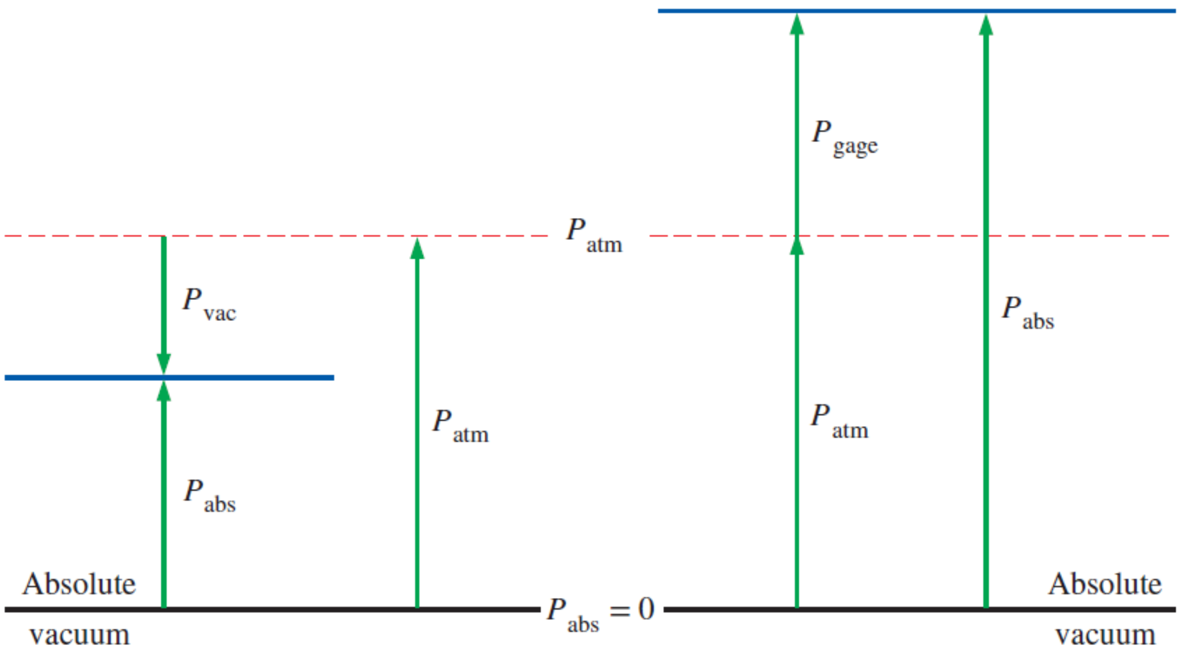


Figure 1-18: Diagram of absolute, gage, and vacuum pressures.

Pressure in a liquid at rest increases linearly with distance from the free surface. In Figure 1-19, the pressure at a depth *h* below the free surface becomes:

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

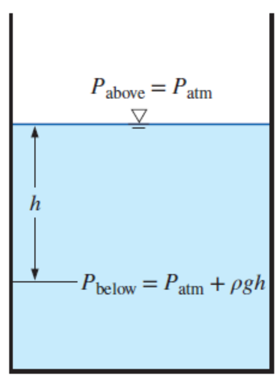


Figure 1-19: Pressure at a specific depth.

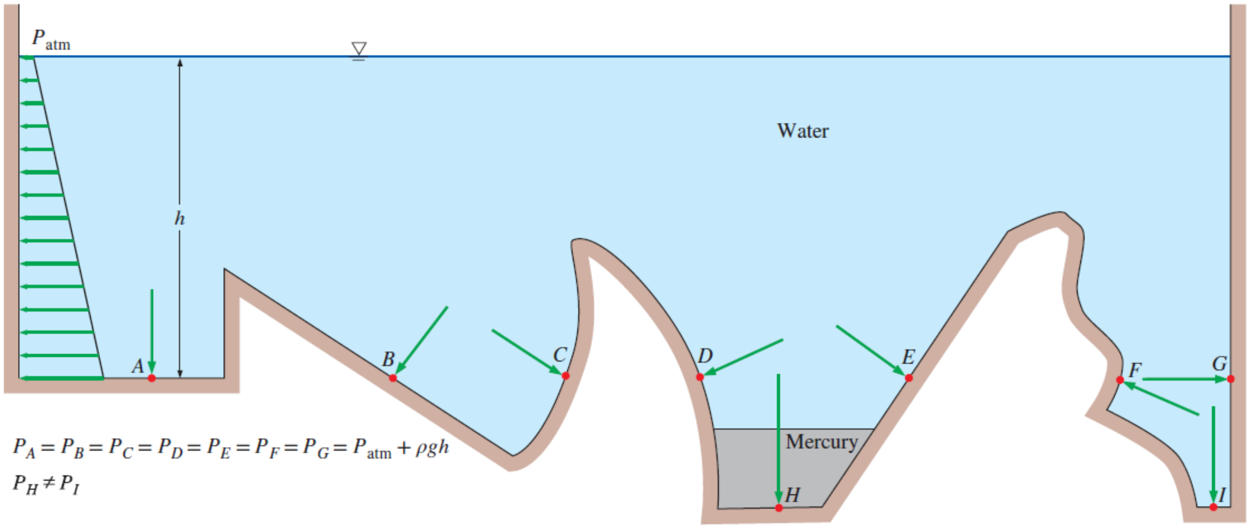


Figure 1-20: Pressure at different points in a specific system.

<u>Pascal's law</u> knew that the force applied by a fluid is proportional to the surface area. A common example of this law is a hydraulic jack.

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

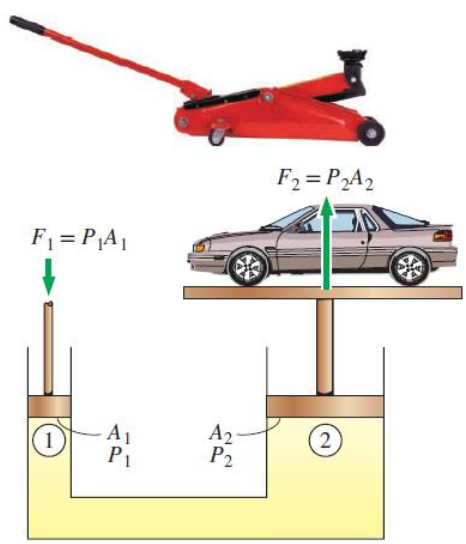


Figure 1-21: Lifting of a large weight by a small force by the application of Pascal's law.