

# MMAE 320 Thermodynamics

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## Thermodynamics

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### I. Relevant Quantities with Explanations

This section highlights useful reference information that is used throughout the following sections and subsections.

Working with pressure, there are three quantities we work with. *Absolute Pressure* is relative to zero pressure. *Gauge Pressure* is relative to ambient atmospheric pressure. *Absolute Pressure* (*air pressure* or *barometric pressure*) is the pressure within the atmosphere of Earth (101,325 Pa).

Pressure is the normal component of force per unit of area:

$$P = \frac{F}{A} \quad (3)$$

Density is described as mass per unit of volume:

$$\rho = \frac{m}{V} \quad (4)$$

Specific volume is described as volume per unit mass. It is an intensive property. It is the reciprocal of density:

$$\nu = \frac{1}{\rho} = \frac{V}{m} \quad (5)$$

$$\nu m = V_{\text{volume}} \quad (6)$$

A Isobaric process is constant pressure. Isothermal constant temperature. Isochoric process is a constant volume.

$$1 \text{ atm} = 760 \text{ mmHg or } 760 \text{ torr} = 101.3 \text{ kPa} \quad (1)$$

We define *Boyle's Law*, *Charles's Law*, *Gay-Lussac's Law*, the *Combined Gas Law*, *Ideal Gas Law*, and *Dalton's Law*. The variables are defined as initial volume  $V_1$ , final volume  $V_2$ , initial pressure  $P_1$ , final pressure  $P_2$ , initial temperature in Kelvin  $T_1$ , and final temperature in Kelvin  $T_2$ .

$$\text{Boyle's Law: } P_1 V_1 = P_2 V_2 \quad (2)$$

$$\text{Charles's Law: } \frac{V_1}{T_1} = \frac{V_2}{T_2} \quad (3)$$

$$\text{Gay-Lussac's Law: } \frac{P_1}{T_1} = \frac{P_2}{T_2} \quad (4)$$

$$\text{Combined Gas Law: } \frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \quad (5)$$

$$\text{Dalton's Law: } P_T = P_1 + P_2 + P_3 + \dots \quad (6)$$

Defining the *Ideal Gas Law*, the pressure in atm, kPa, or mmHg is  $P$ , volume in liters  $V$ , number of moles  $n$ , and the temperature in Kelvin  $T$ .

$$\text{Ideal Gas Law: } PV = nRT \quad (7)$$

The *Ideal Gas Constant* is defined as  $R$ :

$$R = 0.0821 \frac{L \times \text{atm}}{\text{mol} \times K} = 8.31 \frac{L \times \text{kPa}}{\text{mol} \times K} = 62.4 \frac{L \times \text{mmHg}}{\text{mol} \times K} \quad (8)$$

Absolute temperatures defined:

$$K = C + 273.15 \quad (9)$$

$$R = F + 459.67 \quad (10)$$

Pressure definitions:

$$P_{\text{gage}} = P_{\text{abs}} - P_{\text{atm}} \quad (11)$$

$$P_{\text{vac}} = P_{\text{atm}} - P_{\text{abs}} \quad (12)$$

The density of water is  $1000 \text{ kg/m}^3$ . Variation of pressure with depth between two points in the same fluid. *Below* refers to a point at a lower elevation and *above* at a higher elevation:

$$P_{\text{below}} = P_{\text{above}} + pg|\delta Z| \quad (13)$$

The absolute and gage pressures in a liquid open to the atmosphere at a depth of  $h$  from the free surface are:

$$P = P_{\text{atm}} + pgh \quad (14)$$

$$P_{\text{gage}} = pgh \quad (15)$$

## II. SYSTEMS AND CONTROL VOLUMES

### A. Types of Systems

A *system* is a defined quantity of matter or region in space chosen for study. A boundary of a system can be movable or fixed and its surroundings. Systems can be *open*, *closed*, *adiabatic*, and *isolated*.

An open system or a *controlled volume* exchanges mass and energy with its surrounding environment. Open systems involve some valve typically. The boundaries of a control volume are *control surfaces*.

A closed system does not exchange mass but it is able to lose energy or receive it in the form of heat through thermal contact or work performed on the system. A *closed system* or a *control mass* is a system with fixed mass, i.e., no mass can leave or enter. Volume is not required to be fixed in this type of system.

An adiabatic system is thermally isolated and thus no heat transfer occurs. It cannot receive or lose heat, but work can be performed on the system. Processes like compression/expansion are *adiabatic processes*.

An isolated system cannot exchange mass or energy and there is no contact between the system and the environment.

## B. Properties of a System: Intensive and Extensive

Systems contain macroscopic physical characteristics at a point in time which can be *intensive* or *extensive*. Intensive properties depend on mass and extensive properties are independent of mass (the size of a system). Intensive properties consist of pressure P, temperature T, concentration, density, melting point, boiling point, surface tension, viscosity, etc. Extensive properties consist of mass M, volume V, internal energy E or U, heat capacity, enthalpy, entropy, etc. *Specific quantities* can be derived by dividing two extensive quantities

$$\frac{\text{Extensive}_1}{\text{Extensive}_2} = \text{Intensive}_1 \quad (7)$$

which is also the way to go from an extensive quantity to an intensive one:

$$\rho_{\text{intensive}} = \frac{m_{\text{extensive}}}{V_{\text{extensive}}} \quad (8)$$

Specific quantities do not depend on the system size.

## C. Relationships with Pressure and Temperature

The *density* of most gases is directly proportional to pressure and inversely proportional to temperature. The density  $\rho$  of a substance may be given relative to the density  $\rho_{\text{well known}}$  of a well known substance. This is defined as *specific gravity* or *relative density*:

$$\text{Ratio of } \rho_{\text{substance}} \text{ to } \rho_{\text{standard at } T_{\text{specific}}} \quad (9)$$

$$SG = \frac{\rho}{\rho_{H_2O}} \quad (10)$$

Specific weight is defined as the weight of unit volume of a substance ( $N/m^3$ ):

$$\gamma_s = \rho g \quad (11)$$

## III. State and Equilibrium

*Thermal equilibrium* is described as temperature being the same everywhere in a system. *Mechanical equilibrium* is described as no change in pressure with time. In *phase equilibrium*, the mass of each phase remains constant. In *chemical equilibrium*, the chemical composition does not change with time (no reactions).

The state postulate states: "the state of a simple compressible system is completely specified by two independent, intensive properties." The number of properties required to fix the state of matter of a system is best described. The state of a *simple compressible system* is completely specified by two independent, intensive properties. Two properties are independent if one can be varied while the other remains the same. Temperature T and specific volume  $\nu$  are always independent properties and can fix the state of a *compressible system*. Temperature T and pressure P are independent properties for a single phase system, but dependent for multi phase systems.

## IV. Processes and Cycles

A *process* is any change that a system undergoes from one equilibrium state to another. The *path* of a process is a series of states through which a system passes during a process. Thermodynamics processes are

*quasi-static* or *quasi-equilibrium* (*quasi*: seeming apparent, but not really). The external parameters controlling the system change with time as such as low rate that at any snapshot in time, it is very close to the equilibrium, corresponding to the instantaneous values of the control parameters. The external parameters are what define the macroscopic quantities of a system at any point in time and stage in the process represented as a continuous line in space of those quantities, thus the *configurations space*. *Reversible processes* are *quasi-static* processes which can go both ways along the same line in space of thermodynamics quantities—most are reversible. All *non-quasi-static* processes are *irreversible*.

## V. Temperature

The relation between the *Celsius* and *kelvin* scales is:

$$T(C) = T(K) - 273.15 \quad (12)$$

The existence of temperature as the new non-mechanical quantity which equilibrates in the case of systems in thermal contact, is called the *zeroth law of thermodynamics*.

Zeroth Law of Thermodynamics: *If two bodies are in thermal equilibrium with a third body, they are also in thermal equilibrium with each other.* This law deals with thermal equilibrium. Two objects are at the same temperature and thus will not exchange heat flow between them. Temperature is the indicator of thermal equilibrium. A system is a collection of objects we examine. The surroundings are the rest of the universe around that system. Some systems allow heat flow or out and will have a *diathermal walls* (which allows for heat flow). Systems who don't allow heat to flow in or out have *adiabatic walls*. No system can be completely adiabatic.