I. Concepts and Definitions

F. Properties of a system (we use them to calculate changes in energy)

1. A property is a characteristic of a system that can be given a numerical value without considering the history of the system. Examples include T, P, ρ, velocity, E, U, volume (we can only measure T, P, velocity, mass, volume)
2. Examples and definitions
   - a. pressure, P

$$P = \frac{force\ exerted\ by\ fluid}{unit\ area}$$

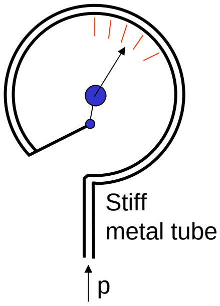
$$P\ (=)\ \frac{N}{m^2} = 1\ pascal = 1\ Pa$$

$$1\ atm = 101325\ Pa = 1.01325\ bar = 14.696\ psia$$

$$1\ bar = 10^5\ Pa$$

   - b. density, ρ $\quad \rho = \frac{mass}{volume} = \frac{m}{V},\ \frac{kg}{m^3}$ (1-4)

I. Concepts and Definitions



Bourdon tube gage gives P_{gage}.

c. atmospheric pressure (absolute) = P_{atm}

d. gage pressure = $P_{gage} = P_{abs} - P_{atm}$ (1-15)

e. absolute pressure = $P_{abs} = P_{atm} + P_{gage}$

f. vacuum pressure = $P_{vac} = P_{atm} - P_{abs}$ (1-16)

g. specific volume = v = $1/\rho$ = Vol/mass, m^3/kg

h. **intensive** properties are independent of the size of the system: T, e, P, ρ, specific volume (v), u. The units on e are kJ/kg.

i. **extensive** properties depend on the size of the system: actual volume (V), E, m, U. The units on E are kJ.

Example. The pressure gage attached to the air storage tank of a compressor reads 100 psi. If the atmospheric pressure of the surroundings is 14.7 psi, what is the absolute pressure in the tank? (Answer: 114.7 psia)

I. Concepts and Definitions

Example. You are designing a snorkel that will allow you to remain submerged in water at a depth of 1 m. Discuss any problems you might experience in using this device.

At depth h = 1 m, the net pressure resisting the expansion of your lungs will be (see Eq. 1-19, p. 24 of text)

$$P = \rho g h = 1000\frac{kg}{m^3}\left(9.81\frac{m}{s^2}\right)1\,m = 9810\frac{N}{m^2} = 1.423\,psi$$

If we approximate that part of the trunk that expands during breathing by a cylinder with diameter d = 30 cm and height L = 30 cm, the curved surface will have area $A = \pi dL = 0.2827\ m^2$. The force acting on your poor trunk, as you try to breath, will be P*A = 2774 N. This corresponds to the force exerted by a mass of 283 kg or 624 lb. Your snorkel will not work at this depth because you will not be able to breath against the force exerted by the water surrounding your body.

I. Concepts and Definitions

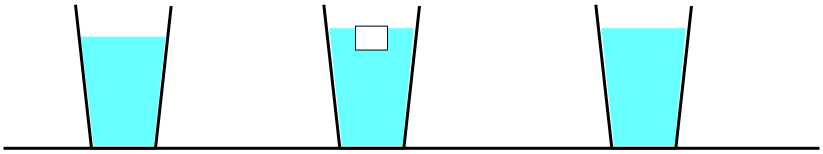
j. temperature

$T(K) = T(^oC) + 273.15$ (1-9)
$T(^oR) = T(^oF) + 459.67 = 1.8\ T(K)$ (1-10, 11)
$1K = 1.8^oR$
$T(^oF) = 1.8\ T(^oC) + 32$ (1-12)
$\Delta T(K) = \Delta T(^oC)$ (1-13)
$\Delta T(^oR) = \Delta T(^oF)$ (1-14)

(1-13) means that a temperature change of 10 degrees K = temperature change of 10 degrees C.

I. Concepts and Definitions

3. The properties of a system at **equilibrium** do not change with time when the system is isolated from its surroundings. Properties are only defined in equilibrium states.



A glass of pure water at room temperature. Thermodynamics can completely describe the state of the water at equilibrium.

Add an ice cube to the water. Thermodynamics cannot describe how long it will take for the ice to melt nor the phenomena that occur during melting.

If we wait long enough the ice will melt and the system will return to a condition of equilibrium.

I. Concepts and Definitions

4. A set of properties that completely describe a system specify the **state** of the system.
5. The State Postulate (an experimental observation, see p. 14)

The intensive state of a pure substance is completely specified by two independent, intensive properties.

a. for example, u = f(T,v). T and v (temperature and specific volume) are always independent, but T and p are not necessarily so. T and p are both intensive properties but in a two-phase region they cannot be varied independently. We will come back to this.

b. independent means that one property can be varied while the other is held constant.

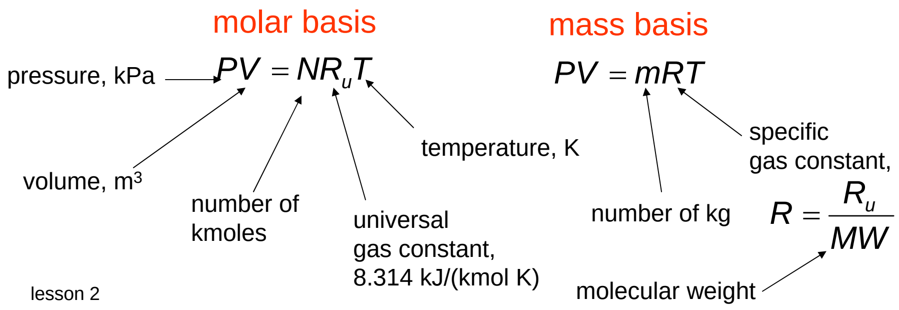
c. pure means that we have a single pure chemical species (dry air is considered pure).

I. Concepts and Definitions

6. Properties of pure substances
   a. Solids and liquids

Solids and liquids are approximately incompressible and that is how we model them. For example, the densities of water at 20°C, and 1 and 300 bar, are 998 and 1011 kg/m^3. Table A-3 gives the properties of solids and liquids.

   b. Ideal gases (low pressure, see p. 137 of text)



molar basis

$$PV = NR_uT$$

pressure, kPa

volume, m^3

number of kmoles

universal gas constant, 8.314 kJ/(kmol K)

temperature, K

mass basis

$$PV = mRT$$

number of kg

specific gas constant,

$$R = \frac{R_u}{MW}$$

molecular weight

I. Concepts and Definitions

c. Density of an ideal gas

There are no tables in the book that give the density of ideal gases. That's because they are so easy to calculate from the ideal gas law.

$$\rho = \frac{mass}{volume} = \frac{m}{V} = \frac{P}{RT} = \frac{P(MW)}{R_uT}$$

Example: the density of air at 25°C and 1 atm is

$$\rho = \frac{P(MW)}{R_uT} = \frac{1\ atm \dfrac{101.3\ kPa}{1\ atm}\left(29\dfrac{kg}{kmol}\right)}{8.314\dfrac{kPa\ m^3}{kmol\ K}(25+273)K} = 1.19\frac{kg}{m^3}$$

Example: the density of air at 0°C and 0.85 atm is

$$\rho = 1.19\frac{kg}{m^3}\left(\frac{0.85\ atm}{1\ atm}\right)\left(\frac{298\ K}{273\ K}\right) = 1.10\frac{kg}{m^3}$$

I. Concepts and definitions

d. Example – one more application of the ideal gas law

Find the mass (kg) and weight (N) of the air contained in a 4.00-m-by-7.00-m-by-8.00-m room if the temperature and pressure of the air are 22.0 C and 0.825 atm.

Assumption: the ideal-gas law applies
Data: R = 0.2870 (kPa m^3)/(kg K) (Table A-1)
g = 9.81 m/s^2 (inside front pages of book)
T = 22 + 273.15 = 295.15 K
Calculations: $PV = mRT$

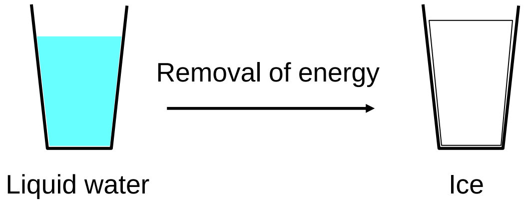
$$m = \frac{PV}{RT} = \rho V = \frac{0.825\ atm \frac{101.325\ kPa}{1\ atm}(4)7(8)m^3}{0.2870 \frac{kPa \bullet m^3}{kg \bullet K}(295.15\ K)} = 0.9868 \frac{kg}{m^3} 224\ m^3 = 221\ kg$$

$$weight = mg = 221(kg)9.81\frac{m}{s^2} = 2170\ N$$

I. Concepts and Definitions

G. Processes and Cycles

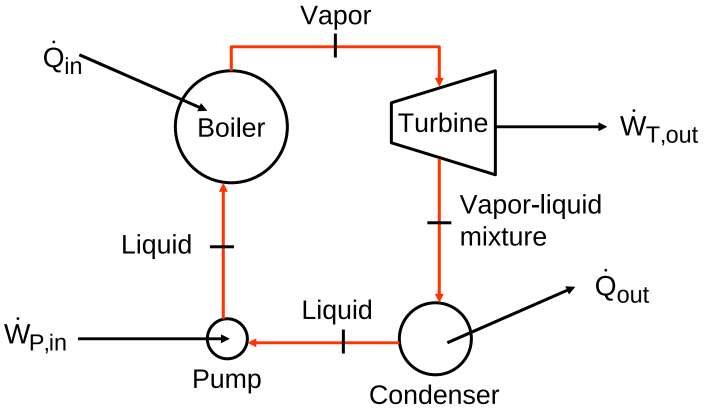
1. A **process** changes a system from one equilibrium state to another.



I. Concepts and Definitions

G. Processes and Cycles

2. A **cycle** is a process that returns a system to its original state. A steam power cycle is an example of a process in which a fluid is alternatively vaporized and condensed.



I. Concepts and Definitions

G. Processes and Cycles

3. A **quasi-equilibrium or reversible process** is one in which the system remains infinitesimally close to equilibrium at all times. This is an idealization that is approximated by many real processes.
4. The intensive properties of a single-phase system undergoing a quasi-equilibrium process are spatially uniform.

Suppose we have a frictionless, piston-cylinder device that is filled with a compressed gas. We flick the particles of sand off the piston one at a time. The gas in the cylinder undergoes a reversible expansion.