School of Engineering, University of Edinburgh
Engineering Thermodynamics (Mechanical) 2

Tutorial 1 – SOLUTIONS

Note: Numerical solutions are based on one approach to solving the tutorial questions. Other approaches can also be correct and could lead to slightly different numerical answers.

Conceptual Questions:

1. Describe the following:
(a) Open system
- *A system in which mass as well as energy can cross the system boundary*

(b) Closed system
- *A system with fixed amount of mass. Energy can cross the system boundary, but mass cannot cross the boundary.*

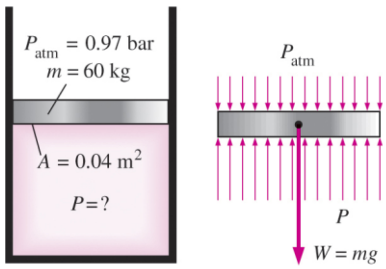
(c) What is the thermodynamic state postulate?
- *The state of the system is completely defined by two independent, intensive properties*

2. Determine whether the following properties are intensive or extensive:
(a) Pressure - *intensive*
(b) Temperature - *intensive*
(c) Mass - *extensive*
(d) Volume - *extensive*
(e) Density - *intensive*
(f) Total energy (E) - *extensive*

Problem Solving Questions:

3) A piston-cylinder device contains a gas at equilibrium. The piston has a mass of 60 kg and a cross-sectional area of 0.04 m^2. The local atmospheric pressure is 0.97 bar (97 kPa), and the gravitational acceleration is 9.81 m/s^2. Assuming that friction between the piston and the cylinder is negligible calculate the absolute pressure inside the cylinder in bar and in kPa. If some heat is transferred to the system and the volume of the gas triples, do you expect the pressure to change?

Solution:
First draw a diagram of the system and note the relevant data from the question.



The absolute pressure P_{abs} inside the cylinder is a sum of the pressure applied by the weight of the piston P_{piston} (that's what a gage would have shown if it had been attached to the gas volume) and the atmospheric pressure P_{atm} pushing on the piston:

Based on the free body diagram:

$P_{abs} = P_{piston} + P_{atm}$
$P_{abs} = mg/A + P_{atm}$
P_{abs} = (60 kg x 9.81 m/s^2)/0.04 m^2 + 0.97 bar x 10^5 Pa/bar
P_{abs} = 14715 Pa + 97000 Pa
P_{abs} = 111715 Pa or 111.7 kPa

P_{abs} = 1.1 bar

[Limit your significant figures to no more than those provided in the question.]

The volume change will have no effect on the free-body diagram drawn above and therefore the pressure inside the cylinder will remain the same.

4) A manometer reading is 100 mmHg (i.e. height of Hg in manometer). A gauge pressure difference using a manometer can be calculated by the following: $\Delta \boldsymbol{P} = \boldsymbol{\rho g h}$ (see lecture 1, slides 38 + 39). Calculate the **gauge** and **absolute** pressure in kPa. The density of mercury is 13,600kg/m^3, gravitational acceleration is 9.81 m/s^2 and atmospheric pressure is 101.3 kPa.

Solution:

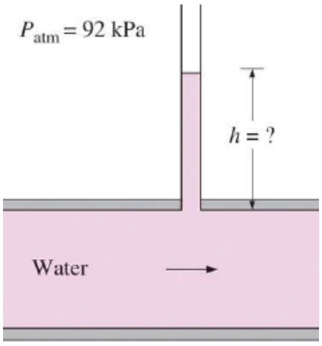
ρ = 13,600kg/m^3
g = 9.81m/s^2
h = 100mm = 0.100m

$\Delta P = P_{gage} = \rho g h$
P_{gage} = 13,600*9.81*0.100
P_{gage} = 13342 Pa or 13.34 kPa

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

P_{abs} = 101.3 kPa + 13.3 kPa
P_{abs} = 114.6 kPa

5) A glass tube is attached to a water pipe at a right angle. If the water pressure at the bottom of the tube is 135 kPa and the local atmospheric pressure is 92 kPa, calculate how high the water will rise in the tube (g = 9.81 m/s^2 and the density of water 1000 kg/m^3). Lecture slide material: lecture 1, slides 38 + 39.



Solution: The weight of the water in the tube is equal to the pressure difference between the pressure in the pipe P_{pipe} and the atmospheric pressure P_{atm}:

$\rho g h = P_{pipe} - P_{atm}$
$h = (P_{pipe} - P_{atm}) / \rho g$ = (135000 Pa – 92000 Pa) /1000 kg/m^3 x 9.81 m/s^2) = 4.4 m
Note: kPa was converted to Pa to obtain consistent units. Always keep track of units!

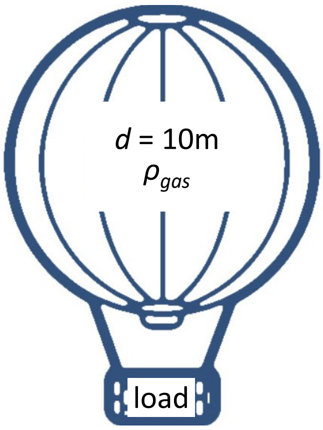
6) A spherical balloon 10 m in diameter is filled with helium at a temperature and pressure of 15°C and 100 kPa. The helium behaves as an ideal gas with a mass-based gas constant R_{Helium} = 2.0771 kJ/kgK. Determine the mass of the helium in the balloon.

Solution:

- $PV = mRT;\ m = PV/RT$
- $V = \frac{4}{3}\pi * r^3 = \frac{4}{3}\pi(5m^3) = 523.6\ m^3$
- $m = 100\ kPa * 523.6\ m^3 \Big/ \left(2.0771 \frac{kJ}{kgK} * 288.15K\right)$
- $m = 87.5\ kg$

7) Consider you want to transport an external load by using a large, spherical-shaped balloon. The buoyancy force (expressed below) is the force that suspends the balloon in the air.

$$F_b = \rho_{air} g V_{balloon}$$



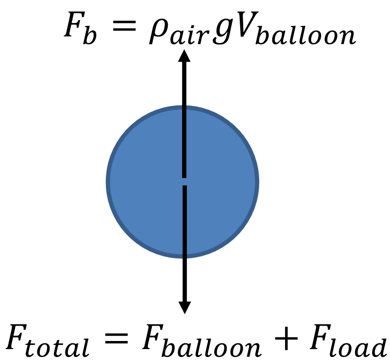
Take the density of air to be 1.16 kg/m³. Determine the maximum load in kg the balloon can support if the balloon is filled with:

(a) Hot air with ρ_{air} = 0.8 kg/m³
(b) Helium (ρ_{Helium} = 0.16 kg/m³)

Hint: do not forget to account for the weight of the balloon gas contents.

Solution:

Draw a free body diagram of balloon



- $\sum F_{vertical} = F_b = F_{weight\ of\ load+balloon}$
- $F_b = \rho_{air} g V_{balloon}\ ;\ F_{load} = m_{load} g$
- $\rho_{air} g V_{balloon} = m_{load} g + \rho_{gas} g V_{balloon}$
- $m_{load} = (\rho_{air} - \rho_{gas}) V_{balloon}$
- $V_{balloon} = \frac{\pi}{6} d^3$

(a) $m_{load} = (1.16\ kg/m^3 - 0.8\ kg/m^3) * \frac{\pi}{6}(10m)^3 =$ 188.5 kg

(b) $m_{load} = (1.16\ kg/m^3 - 0.16\ kg/m^3) * \frac{\pi}{6}(10m)^3 =$ 523.6 kg

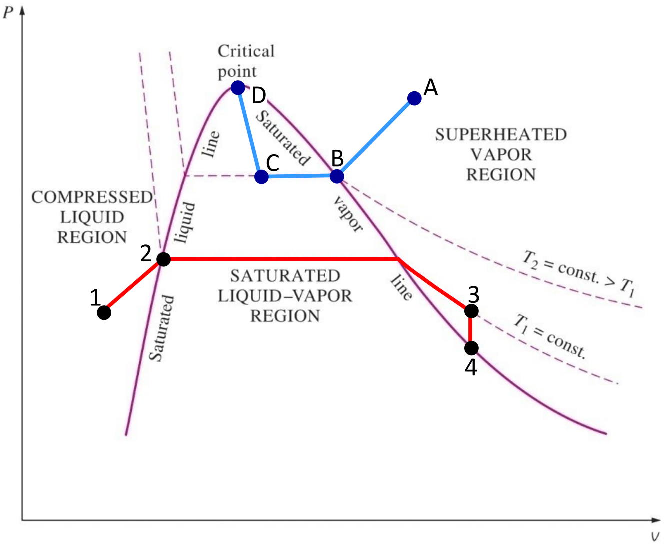
8) Plot the following processes in the P-v diagram. Starting points can be arbitrarily placed in the specified regions.

<u>Process 1-2-3-4</u>

- 1→2: linear increase in P & v from compressed liquid to saturated liquid.
- 2→3: *v* increase to superheated vapor under constant T.
- 3→4: P decrease to saturated vapor under constant *v*.

<u>Process A-B-C-D</u>

- A→B: linear P & v decrease from superheated vapor to saturated vapor
- B→C v decrease to saturated mixture with *x* = 50% under constant P & T
- C→D: P increase (& possible *v* decrease) to critical point



<u>Note</u>: slight differences in location expected if starting point is placed in another location within the specified region. Trends should be same, however.