



CEEN 501 Thermal Energy Systems

Quiz #1 (September 30, 2013)

Name _____

Student # _____

- For multiple choice questions, please circle the single best answer.
- Closed book & closed computer.
- Calculator required.
- Show all your work on these pages (no extra pages please).
- Return the unit conversion and properties package.
- You can keep the formula sheet.
- There are seven (7) questions with point distribution as follows:

<u>problem</u>	<u>points</u>
1	5
2	5
3	5
4	5
5	10
6	10
7	15
total	55



The rationale for the first two questions is that I believe energy engineers should be able to describe what is meant by heat (thermal energy) and work to anyone who asks, whether a technical person or lay person.

1. In thermodynamics, the definition of thermal energy (heat) is:

CCT definition is "form of energy that is transferred between two systems (or a system and its surroundings) by virtue of a temperature difference"

Key ideas:

- It is the specific form of energy that moves due to a temperature difference
- it is a *transfer* of energy; it is energy in *transition* at the system boundary

2. In thermodynamics, the definition of work is:

Per CCT "if the energy crossing the boundary of a closed system is not heat, it must be work"

Per Schroeder "any other *transfer* of energy into or out of a system"

Alternative definition per Sonntag & Van Wylen (1982) "work is done by a system if the sole effect on the surroundings (everything external to the system) could be the raising of a weight."

Key ideas:

- Work is all other forms of energy that are not due to a temperature difference. Alternately, the equivalent raising of a weight definition
- work is a *transfer* of energy; it is energy in *transition* at the system boundary
- work refers to multiple forms of energy, often characterized as force times distance

3. A glass of water sitting on a table at 20°C in a room at sea level is:

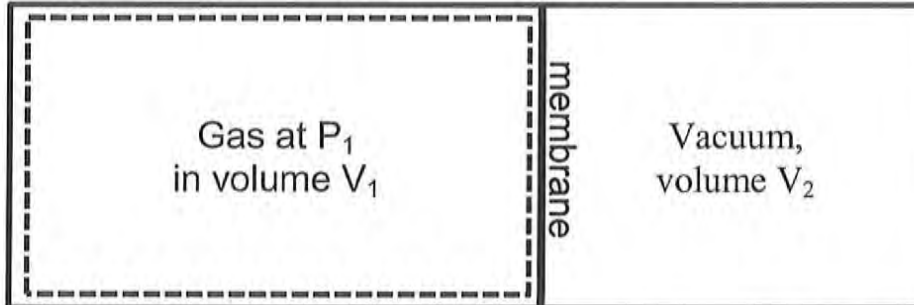
- a. Saturated liquid
- b. Compressed liquid
- c. Two phase system
- d. It cannot be determined from the information provided

Saturation temperature at sea level is 100°C, so at the lower temperature of 20°C it must be a compressed liquid.

This was a very easy and basic question. If you did not get this correct, you really need to read the textbook and improve your understanding of thermodynamic properties.



4. Consider an adiabatic (well-insulated) gas in a tank with two sections. The gas section is separated from a vacuum section by a membrane. A process occurs where the membrane ruptures and the gas fills the entire volume. Neglect any work associated with rupturing the membrane, and consider the gas as the system. What is the work involved with this process?



- Because no heat is added, the work will be greater than zero and calculated as the change in internal energy.
- Work is calculated as $W_b = \int_1^2 P dV$ because there is a change in volume
- The work is zero because there is no resistance at the interface where the system boundary expands.
- There is insufficient information to determine the boundary work from this process.

It is tempting to want to integrate and calculate a work term. However, in this case, there is no work at the boundary. As an example, consider CCT problem 4-81 which shows a similar problem and the solution involves no work.

This question is also an example why thinking and reasoning are critical skills in thermodynamics (as well as any other body of knowledge). It is easy for us engineers to plug numbers into formulas to produce numerical results.

Further reflection on Quiz 1, Problem #4.

From Shroeder's Thermal Physics (2000)

A very different way of letting a gas expand is shown in Figure 2.14. Initially, the gas is separated by a partition from an evacuated chamber. We then puncture the partition, letting the gas freely expand to fill the whole available space. This process is called **free expansion**. How much work is done during free expansion? None! The gas isn't pushing *on* anything, so it can't do any work. What about heat? Again, none: No heat whatsoever flowed into or out of the gas. Therefore, by the first law of thermodynamics,

$$\Delta U = Q + W = 0 + 0 = 0. \quad (2.52)$$

The energy content of the gas does not change during free expansion, hence formula 2.51 applies. This time, however, the entropy increase was *not* caused by the input of heat; instead we have manufactured *new* entropy, right here on the spot.

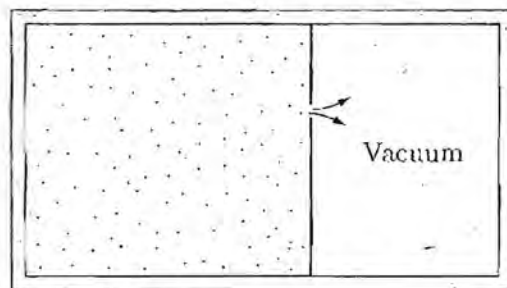


Figure 2.14. Free expansion of a gas into a vacuum. Because the gas neither does work nor absorbs heat, its energy is unchanged. The entropy of the gas increases, however.

A good question was posed in class: **what would the temperature be after the expansion?** From thermal physics, if a gaseous system contains N molecules, each with F degrees of freedomⁱ without any other forms of energy other than translation, rotation and spring energy (all in the quadratic form $\frac{1}{2}ab^2$) then the internal energy isⁱⁱ $U = \frac{1}{2}kT F N$

If the gas is expanded without changing the internal energy or number of molecules, then the formula above predicts there would be no change in temperature. Put another way, if $U_1 = U_2$ and $N_1 = N_2$ for the same gas, the above equation predicts $T_1 = T_2$.

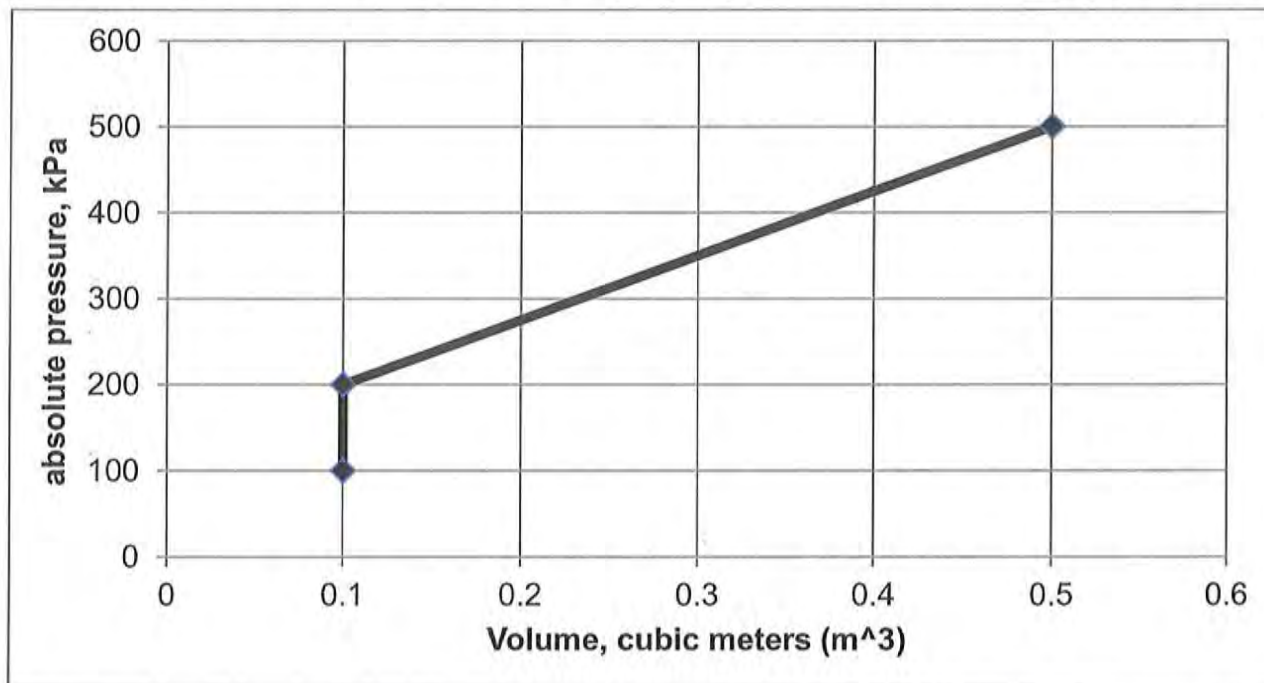
Finally, if the gas is an ideal gas, then the ideal gas law, $PV = mRT$, predicts that $P_1V_1 = P_2V_2$ so that the final pressure would be: $P_2 = \frac{P_1V_1}{V_2}$

ⁱ "degrees of freedom" is used to describe each form of energy that applies at the molecular level. It would include translation motion in 3 directions, possibly rotational motion, vibration, and elastic potential energy. Oloman (2009) defines internal energy as a "catch all" term, and these forms of energy that are counted at the molecular level comprise the various forms of energy that, collectively, are described as internal energy (U) in thermodynamics. For a monatomic gas (like argon), $F = 3$. For a diatomic gas (like nitrogen), $F = 5$.

ⁱⁱ k Boltzmann's constant, T = temperature



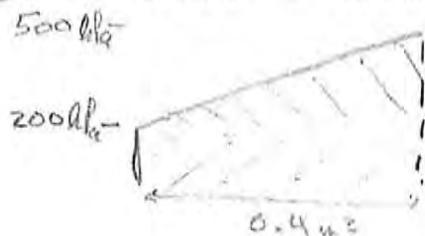
5. A closed system undergoes two quasi-equilibrium processes shown in the chart below. Calculate total work produced by this series of processes in units of kJ.



The basic concept of area under the curve was introduced in CCT chapter 3. It is also critical to note that in thermodynamics, as a general rule, we always use absolute pressure unless otherwise specified (see CCT p. 38).

Note: CCT p. 38. In thermodynamics, absolute pressure is used, unless otherwise specified.

⑤ Work = area under P-V curve.



e.g. See Figure 3-21 in CCT

$$(0.4 \text{ m}^3)(200 \text{ kPa}) + \frac{1}{2}(0.4 \text{ m}^3)(300 \text{ kPa}) = 140 \text{ kPa} \cdot \text{m}^3$$

$$W = 140 \text{ kJ}$$

- 3 pts if subtracted atm pressure



6. Ethane (C_2H_6) is contained in a rigid vessel at 80 psia and 540 °F. Verify whether or not the ideal gas relation, $Pv = RT$, can be used with acceptable accuracy.

⑥ ethane Table A-1E
 $T_{CR} = 549.8 \text{ R}$
 $P_{CR} = 708 \text{ psia}$

$$T_R = \frac{(540 + 459.67) \text{ R}}{549.8 \text{ R}} = 1.82$$

$$P_{CR} = \frac{80 \text{ psia}}{708 \text{ psia}} = 0.113$$

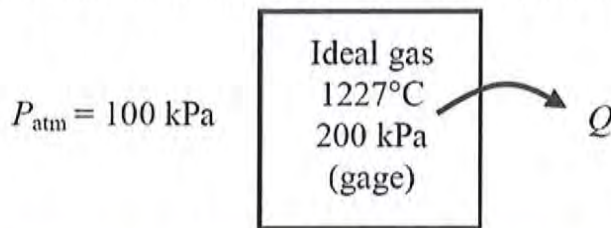
Criteria $P_R \leq 10$ and $T_R \geq 2$

∴ do not use $Pv = RT$

do use $Pv = ZRT$



7. A rigid tank contains an ideal gas at 1227 °C and 200 kPa gage pressure. The gas is cooled until the gage pressure reads 50 kPa. If the atmospheric pressure is 100 kPa, determine the final temperature of the gas.



Similar to problems 5 and 6, a surprising number of students did not use absolute pressure and temperature values. This is fundamental to thermodynamic calculations.

⑦

$$m_1 = m_2$$

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

also $V_1 = V_2$ (constant volume)

$$\therefore \frac{P_1}{T_1} = \frac{P_2}{T_2}$$

$$T_2 = T_1 \left(\frac{P_2}{P_1} \right) = (1227 + 273.15) \text{ K} \frac{(50 + 100) \text{ kPa}}{(200 + 100) \text{ kPa}}$$

$$T_2 = 750.08 \text{ K} \quad \text{or} \quad 476.9 \text{ } ^\circ\text{C}$$

$T_2 = 477 \text{ } ^\circ\text{C}$