

### PRACTICE QUIZ 3

All students must work independently. You are allowed one page of handwritten notes only; no communication devices (cell phones, etc) permitted. Show all work; no credit will be given for answers with no derivation. Any problem asking for a vector (e.g., force) requires a vector as an answer!

**Directions:** Work each problem on the exam sheet provided. Put your NAME and PID on EACH sheet (one for each problem) in the space provided. If you don't have enough room on a single side of the page, finish the problem on the back of the page.  $15 + 20 + 15 + 15 + 4(3) = 77$  points total for this exam.

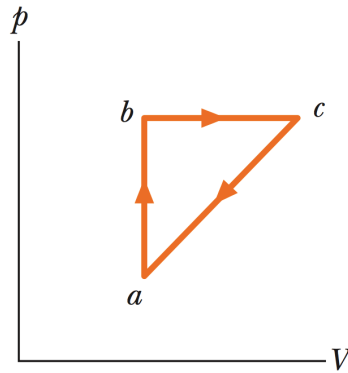
Please keep in mind the following before you turn in your exam to avoid a 10% penalty:

- Make sure your name and PID are on each sheet in the space provided.
  - Turn in all 6 pages. Do not turn in this cover page. If you absolutely could not fit a problem on the front/back of a single sheet, clearly communicate this to the proctor/TA/instructor when you turn in your exam.
  - Make sure your pages are in numerical order (page 1, page 2, page 3, etc.)
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Name:

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1. (15 points, 5 points each): The following graph shows a new kind of car engine. Suppose that  $(p, V) = (p_0, V_0)$  at point  $a$ , and  $(p, V) = (2p_0, 2V_0)$  at point  $c$ . A diatomic gas with rotational but not vibrational modes excited (throughout the entire cycle) moves from  $a$  to  $b$  to  $c$  and straight back to  $a$  as shown:



Your answers to the following should be in terms of  $p_0$  and  $V_0$  alone.

- Find the heat added to the gas for all three steps of the cycle (positive if heat is added to the gas, negative if heat leaves the gas).
- Find the efficiency of this engine.
- Find the maximum efficiency possible for any engine running between these two temperatures.

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2. (20 points, 5 points each): A refrigerator operates via the following 3-step cycle:

- An isothermal expansion to four times its initial volume. ( $A \rightarrow B$ )
  - An adiabatic compression that cuts the volume in half. ( $B \rightarrow C$ )
  - An isobaric process that cuts the volume in half again, returning to the initial point. ( $C \rightarrow A$ )
- (a) Draw this cycle on a (labelled)  $pV$  diagram. Call the initial volume and pressure  $V_0$  and  $p_0$ . By "labelled," we mean axes, points, processes, and direction of the cycle (arrow on each process). For each point, it should be clear what the volume and pressure are in terms of  $p_0$  and  $V_0$ .
- (b) Solve for the adiabatic constant for this gas. This value is actually impossible (in three dimensions). Explain why.
- (c) Find the Carnot coefficient of performance for any refrigerator operating between these two temperature extremes.
- (d) You don't have to solve for the actual coefficient of performance of this refrigerator<sup>1</sup>, but explain which heat(s) from which step(s) you would use to plug into  $Q_C$  for the formula  $K = Q_C / W$ .

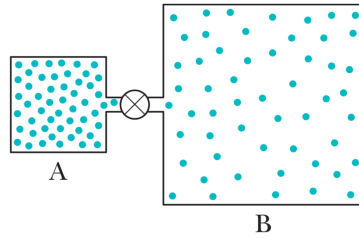
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<sup>1</sup>Actually, you'd get a value bigger than  $K_{\text{Carnot}}$  because of the issue raised in part (b)

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3. (15 points, 5 points each) Rigid container A is in thermal equilibrium with rigid container B. Energy in the form of heat is allowed to transfer between the two containers, but no particles are allowed to pass through. Container A is filled with Argon (Ar, 39.95 g/mol); container B is filled with Oxygen molecules that can rotate but not vibrate ( $O_2$ , and the molar mass of an Oxygen atom is 16.00 g/mol). The volume of container B is five times larger than that of container A. Both containers have the same number of molecules.



- (a) If the pressure in container A is  $p_A$ , what is the pressure in container B? Your answer should be in terms of  $p_A$  alone.
- (b) If the rms speed of gas molecules in container A is  $v_A$ , what is the rms speed of molecules in container B? Your answer should be in terms of  $v_A$  alone.
- (c) If the total thermal energy in container A is  $E_{th,A}$ , what is the total thermal energy in container B? Your answer should be in terms of  $E_{th,A}$  alone.

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4. (15 points, 5 points each) 1.00 mol of diatomic gas adiabatically expands such that it cools from 300.0 K to 270.0 K. Assume that, throughout the expansion, rotational modes are excited in the gas, but not vibrational modes. The initial volume of the gas is  $V_0$ .
- (a) Find the amount of work that the gas does on its surroundings. You should be able to get a number (your answer should not depend on  $V_0$ ).
  - (b) Find the final volume of the gas in terms of  $V_0$ .
  - (c) Suppose, instead, it was 1.00 mol of monoatomic gas that adiabatically expanded such that  $T_i = 300.0$  K to  $T_f = 270.0$  K (also with initial volume  $V_0$ ). Does this gas do more work on its surroundings, or less? Explain using a  $pV$  diagram.

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(12 points, 3 points each): 4 Multiple-choice questions / fill-in-the-blanks on various topics.

Directions for multiple-choice questions: COMPLETELY FILL IN THE SQUARE for the answer.

Directions for fill-in-the-blank questions: Your answer should be entirely in the boxed region. Include the number of significant figures ("sig. figs.") requested in the problem.

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5. Which of the following statements regarding engines and refrigerators is FALSE?

- ☐ It is impossible to construct a refrigerator that takes energy in the form of heat from a low temperature reservoir and delivers the same amount of energy to a high temperature reservoir.
- ☐ You can cool the kitchen by leaving the refrigerator door open.
- ☐ You can heat the kitchen by leaving the oven open.
- ☐ In a refrigerator, you can take out more energy in the form of heat than work that you put in.

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6. The engine in your car takes in heat to do work. For every 100.0 kJ of energy in the form of heat that your car takes in, it does 20 kJ of work, and spits out 80.0 kJ in the form of heat. The lower heat reservoir of the engine is 300.0 K. What is the temperature of the hot reservoir, assuming your car is a perfect Carnot engine? If your car is not a perfect Carnot engine, is the hot reservoir actually warmer or colder than this?

- ☐ 1500 K, warmer.
- ☐ 1500 K, colder.
- ☐ 600 K, colder.
- ☐ 380 K, colder.
- ☐ 380 K, warmer.

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7. The surface temperature of a star is 8530 K, and the power output of the star is  $5.34 \times 10^{26}$  W. Assuming the star is a perfect blackbody, what is the radius of the (spherical) star? (express your answer in meters to 3 sig figs).

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8. Two containers (A and B) initially hold 10 balls. Once a second, one of the balls is chosen at random and switched to the other container. After a long time has passed, you record the number of balls in each container every second. In 100,000 s, approximately how many times do you expect to find that all the balls were in container A?

☐ 1,000

☐ 100

☐ 10

☐ 1

☐ 0

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