

Please write your CID here \_\_\_\_\_

No time limit. One 3x5 note card (handwritten, both sides). No books. Student calculators OK.

Constants which you may or may not need:

$g = 9.8 \text{ m/s}^2$	Density of aluminum: $2700 \text{ kg/m}^3$	Specific heat of copper: $387 \text{ J/kg}\cdot^\circ\text{C}$
$G = 6.67 \times 10^{-11} \text{ N}\cdot\text{m}^2/\text{kg}^2$	Linear exp. coeff. of aluminum: $24 \times 10^{-6} /^\circ\text{C}$	Latent heat of melting (water): $3.33 \times 10^5 \text{ J/kg}$
$k_B = 1.381 \times 10^{-23} \text{ J/K}$	Linear exp. coeff. of copper: $17 \times 10^{-6} /^\circ\text{C}$	Latent heat of boiling (water): $2.26 \times 10^6 \text{ J/kg}$
$N_A = 6.022 \times 10^{23}$	Linear exp. coeff. of steel: $11 \times 10^{-6} /^\circ\text{C}$	Latent heat of boiling (liquid nitrogen): $1.98 \times 10^5 \text{ J/kg}$
$R = k_B \cdot N_A = 8.314 \text{ J/mol}\cdot\text{K}$	Specific heat of water: $4186 \text{ J/kg}\cdot^\circ\text{C}$	Thermal conduct. of aluminum: $238 \text{ J/s}\cdot\text{m}\cdot^\circ\text{C}$
$\sigma = 5.67 \times 10^{-8} \text{ W/m}^2\cdot\text{K}^4$	Specific heat of ice: $2090 \text{ J/kg}\cdot^\circ\text{C}$	Thermal conduct. of copper: $397 \text{ J/s}\cdot\text{m}\cdot^\circ\text{C}$
Density of water: $1000 \text{ kg/m}^3$	Specific heat of steam: $2010 \text{ J/kg}\cdot^\circ\text{C}$	
Density of air: $1.29 \text{ kg/m}^3$	Specific heat of aluminum: $900 \text{ J/kg}\cdot^\circ\text{C}$	

Conversion factors which may or may not be helpful:

1 inch = 2.54 cm	1 atm = $1.013 \times 10^5 \text{ Pa} = 14.7 \text{ psi}$	$T_F = \frac{9}{5}T_C + 32$
1 m <sup>3</sup> = 1000 L	1 eV = $1.602 \times 10^{-19} \text{ J}$	$T_K = T_C + 273.15$

Other equations which you may or may not need to know:

$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$	Surface area of sphere = $4\pi r^2$	Volume of sphere = $(4/3)\pi r^3$
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**Instructions:**

- Record your answers to the multiple choice questions (“Problem 1” on the next page) on the bubble sheet.
- To receive full credit on the worked problems, please show all work and write neatly.
- In general, to maximize your partial credit on worked problems you get wrong it’s good to solve problems algebraically first, then plug in numbers (with units) to get the final answer. Draw pictures and/or diagrams to help you visualize what the problems is stating and asking, and so that your understanding of the problem will be clear to the grader.
- Unless otherwise instructed, give all numerical answers for the worked problems in SI units, to 3 or 4 significant digits. For answers that rely on intermediate results, remember to keep extra digits in the intermediate results, otherwise your final answer may be off. Be especially careful when subtracting two similar numbers.
- Unless otherwise specified, treat all systems as being frictionless (e.g. fluids have no viscosity).

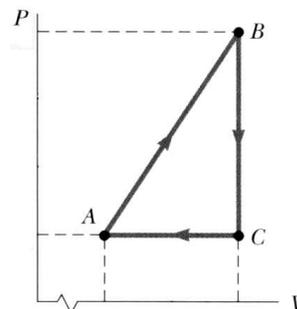
Scores: (for grader to fill in)	
Problem 1 _____	Problem 5 _____
Problem 2 _____	Problem 6 _____
Problem 3 _____	Problem 7 _____
Problem 4 _____	Extra Credit _____
	<b>Total</b> _____

Did you write down your CID at the top of the page? \_\_\_\_\_ If not, you may not get this test booklet back.

(15 pts) **Problem 1:** Multiple choice conceptual questions. **Fill in your answers on the bubble sheet.**

- 1.1. You have two balloons, one filled with air and one filled with helium. If you put both balloons into a tub of liquid nitrogen, which one will end up with the largest volume?
- the air balloon
  - the helium balloon
  - they will end up with the same volume
- 1.2. A pool is filled half with water and half with a light oil (density  $600 \text{ kg/m}^3$ ). The oil floats on the water. When a diver comes up from the bottom of the pool, from the water into the oil, she will experience a buoyant force in the oil that is \_\_\_\_\_ the buoyant force she felt in the water.
- greater than
  - less than
  - the same as

- 1.3. For the next three problems, consider the cyclic process described by the figure. For A to B: is  $W_{\text{on gas}}$  positive, negative, or zero?
- Positive
  - Negative
  - Zero



- 1.4. For B to C: is heat added or taken away from the gas?
- Added
  - Taken away
  - Neither ( $Q_{\text{added}} = 0$ )
- 1.5. For C to A: does the internal energy increase, decrease, or stay the same?
- Increase
  - Decrease
  - Stays the same ( $\Delta E_{\text{int}} = 0$ )

- 1.6. The figure shows a circular piece of steel with a gap. When the steel is heated, the width of the gap:
- decreases
  - increases
  - stays the same



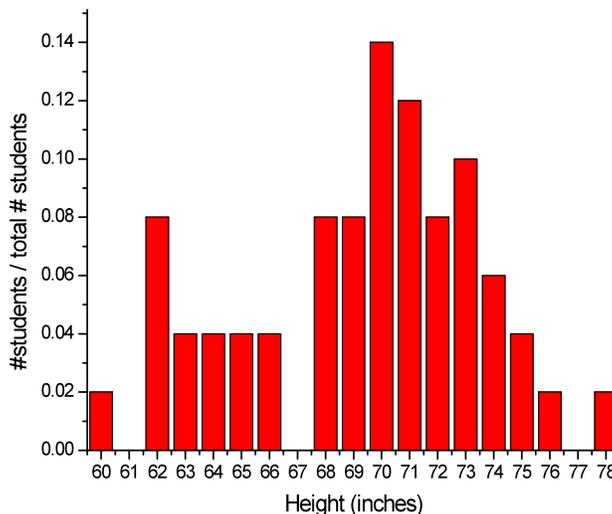
- 1.7. How many degrees of freedom is a  $\text{CH}_4$  molecule likely to have at room temperature? (That is a molecule that has a carbon atom at the middle of a tetrahedron, with 4 hydrogen atoms sticking out from the carbon in four different directions along the points of the tetrahedron.)
- |      |      |
|------|------|
| a. 0 | f. 5 |
| b. 1 | g. 6 |
| c. 2 | h. 7 |
| d. 3 | i. 8 |
| e. 4 | j. 9 |

- 1.8. Bernoulli's Law is a statement of:
- conservation of energy
  - conservation of (regular) momentum
  - conservation of angular momentum
  - conservation of mass/volume
  - probability
  - none of the above

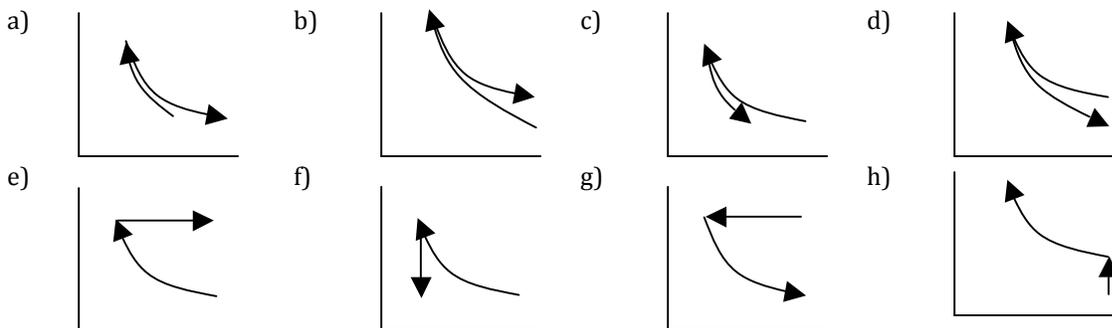
- 1.9. The first law of thermodynamics is a statement of:
- conservation of energy
  - conservation of (regular) momentum
  - conservation of angular momentum
  - conservation of mass/volume
  - probability
  - none of the above

- 1.10. The second law of thermodynamics is a statement of:
- conservation of energy
  - conservation of (regular) momentum
  - conservation of angular momentum
  - conservation of mass/volume
  - probability
  - none of the above
- 1.11. As an airplane flies horizontally at a constant elevation, the pressure above a wing is \_\_\_\_\_ the pressure below the wing.
- larger than
  - smaller than
  - the same as
- 1.12. A plastic cube and a metal cube of the same size and shape are put into water. The plastic cube floats; the metal cube sinks. On which cube is the bouyant force the largest?
- plastic
  - metal
  - same bouyant force

- 1.13. This normalized histogram was created from 50 students in a physics class. If you pick a student at random, what are the chances he/she will be between 61 and 67 inches tall?
- 0 – 10%
  - 10 – 20%
  - 20 – 30%
  - 30 – 40%
  - 40 – 50%
  - 50 – 60%
  - 60 – 70%
  - 70 – 80%
  - 80 – 90%
  - 90 – 100%



- 1.14. As I'm taking data in my lab, I typically average data for 1 second per point. Suppose I decide to average the data for 2 seconds per point instead. How much better is my signal-to-noise ratio likely to be?
- the same
  - $\sqrt{2}$  times better
  - 2 times better
  - 4 times better
  - 8 times better
- 1.15. First, heat is added to a gas while keeping its volume constant, increasing its temperature to  $2.5\times$  the original value. Next, the gas is compressed to 40% of its original value while keeping the temperature constant. Which of the following diagrams best represents the two processes on a standard P-V diagram?



(10 pts) **Problem 2.** (a) You have a 1.003 cm diameter steel ball which you desire to pass through a 1.000 cm inner diameter aluminum ring. Both are at  $50^\circ\text{C}$ . If you heat up only the ring, how hot does it need to get ( $^\circ\text{C}$ )?

(b) A typical 100 W incandescent light bulb has a tungsten filament which is at a temperature of 3000 K. Typically, of the 100 W that goes into the bulb, 97.4 W of heat is conducted or convected away, and only 2.6 W is radiated as light (and most of that is invisible infrared light—now you see why incandescent lights are so inefficient). If you assume the emissivity of the filament to be 0.4, what is the filament's surface area?

(10 pts) **Problem 3.** A heat pump pumps heat from outside your house ( $10^{\circ}\text{C}$ ) to inside your house ( $20^{\circ}\text{C}$ ). It pumps heat into your house at a rate of 2000 J per cycle.

(a) What is the theoretical limit for the heat pump's coefficient of performance?

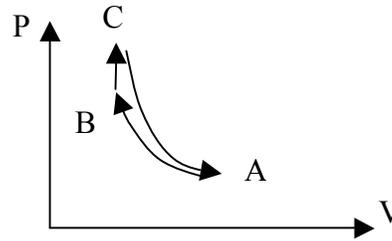
(b) The actual COP is 3.5. How much work per cycle is required to operate the heat pump?

(c) How much heat per cycle is removed from the great outdoors?

(12 pts) **Problem 4.** You add 200 g of copper at 150°C to 300 g of water at 30°C. The water is in a nifty foam container which completely insulates the water and copper from any outside heat and doesn't absorb any heat itself. What is the final temperature of the water/copper mixture?

(20 pts) **Problem 5.** An engine using 0.2 moles of a monatomic ideal gas is driven by this cycle: starting from state A (150 kPa, 350 K), the gas is compressed isothermally until it reaches state B at 400 kPa. Then, the gas is heated at constant volume until it reaches state C. Finally, the gas is expanded adiabatically back to the original state.

	P (kPa)	V (m <sup>3</sup> )	T (K)
A	150		350
B	400		350
C			



(a) Find the unknown P's and T's for all three states. (Hint: it's probably easiest to find them in the order listed.)

state A volume:

state B volume (= state C volume):

state C temperature: (Hint: figure out/use the adiabatic relation between T and V to connect states A and C. Warning: be careful! If you get this part wrong, you will likely miss three of the next five questions.)

state C pressure: (Hint: after you get this answer, it's probably worth taking a minute or two and using it to double-check your answer to the state C temperature. If you did things right then, your answer here should satisfy the normal adiabatic relation between P and V that connects states A and C.)

**Problem 5, cont.**

(b) Find the heat added to the gas during each of the three legs.

A-B

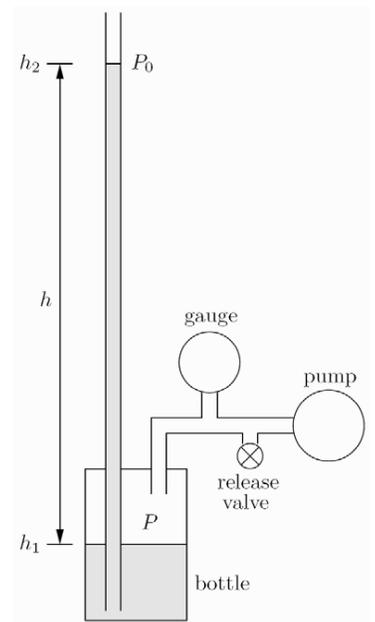
B-C

C-A

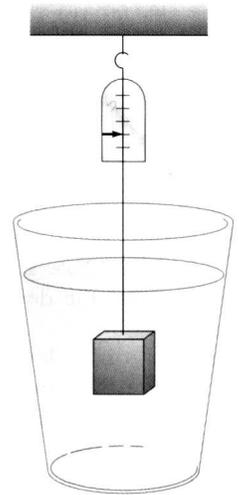
(c) What is the efficiency of an engine using this cycle? Hint: Use the heats you just found in part (b) to identify  $Q_h$  and  $Q_c$ .

(11 pts) **Problem 6.** (a) Use the ideal gas law to figure out the density of air at 400K at 1 atm. (The average molar mass of air molecules is 0.029 kg/mol.)

(b) In Lab 1, you used a contraption like this to measure the density of an unknown liquid. Suppose after pressurizing the bottle you measure  $h = 75$  cm and the gauge pressure to be 1.5 psi (not the absolute pressure  $P$ ). What was the density of the liquid?

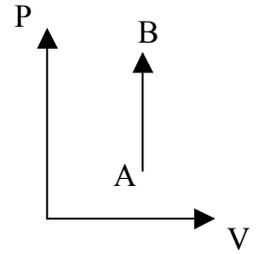


(11 pts) **Problem 7.** (a) A 3 kg block of metal is suspended from a scale and immersed in water as in the figure. The dimensions of the block are 12 cm  $\times$  10 cm  $\times$  8 cm. What will be the reading of the spring scale? (I.e. what will be the tension in the string holding up the block?)



(b) What gauge pressure (not absolute pressure) must a pump generate to get a jet of water to leave its nozzle with a speed of 10 m/s at a height of 3 m above the pump? Assume that the area of the nozzle is *very small* compared to that of the pipe near the pump.

(11 pts) **Problem 8.** Heat is added to 4 moles of a diatomic ideal gas at 300K, while keeping its volume constant as shown in the diagram. This causes the temperature to increase to 900K. (a) What is the change in entropy of the gas?



(b) If the heat came in from a reservoir kept at 950K, what was the change in entropy of the universe? Hint 1: It's the sum of  $\Delta S_{\text{gas}}$  and  $\Delta S_{\text{reservoir}}$ ... and it had better end up positive! Hint 2: Finding  $\Delta S_{\text{reservoir}}$  is a constant temperature problem. You may assume that  $|Q_{\text{lost by reservoir}}| = |Q_{\text{gained by gas}}|$ .

(4 pts; no partial credit) **Extra Credit 1.** If you flip 40 coins, what is the probability of getting exactly 12 heads?

(4 pts; no partial credit) **Extra Credit 2.** Suppose an atom has only three available energy levels, which are at these energies: state 1 = 0 eV; state 2 = 0.2 eV; state 3 = 0.5 eV. (The conversion between eV and joules is found on page 1 of the exam.) If the temperature is 1000 K, what is the probability that the atom is in the lowest energy state?