Name ______________________________________ Box Number ________________

Section ________________

Problem 1 (34 points) ________________

Problem 2 (33 points) ________________

Problem 3 (33 points) ________________

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Total (100 points) ________________

INSTRUCTIONS

- **Closed book/notes exam. (Unit conversion page provided)**
- **Help sheet allowed. (8-1/2 x 11" sheet of paper, one side)**
- **Laptops may be used; however, no pre-prepared worksheets or files may be used.**

1) Show all work for complete credit.
    - **Start all problems at the ANALYSIS stage**, but clearly label any information you use for your solution.
    - **Problems involving conservation principles MUST CLEARLY IDENTIFY THE SYSTEM IN A SEPARATE DRAWING and show a clear, logical progression from the basic principle(s).**
    - **Don't expect us to read your mind** as to how or why you did something in the solution. Clearly indicate how you arrived at your answer and how you used the given information in the process.
    - **Always crunch numbers last on an exam**. The final numerical answer is worth the least amount of points. (Especially if all we would have to do is plug in the numbers into a well-documented solution.)
2) Useful Rule of Thumb (Heuristic): (100 point exam)/(50 min) ≈ 2 points/minute. That means a 10 point problem is not worth more than 5 minutes of your time (at least the first time around).
3) Please remain seated until the end of class or everyone finishes. (Raise your hand and I'll pick up your exam if you have other work you need or want to do.)
4) Always strive to be as good a person as your dog thinks you are.

USEFUL INFORMATION	**SI**	**USCS**	Molar Mass [kg/kmol; lbm/lbmol]	
Ideal Gas Constant: R_u	= 8.314 kJ/(kmol-K)	= 1545 (ft-lbf)/(lbmol-R)	Air	28.97
		= 1.986 Btu/(lbmol-R)	O_2	32.00
Standard Acceleration of Gravity: g	= 9.810 m/s^2	= 32.174 ft/s^2	N_2	28.01
Density of liquid water	= 1000 kg/m^3	= 62.4 lbm/ft^3	H_2	2.016
		= 1.94 slug/ft^3	CO_2	44.01

Length

1 ft = 12 in = 0.3048 m = 1/3 yd

1 m = 100 cm = 1000 mm = 39.37 in = 3.2808 ft

1 mile = 5280 ft = 1609.3 m

Mass

1 kg = 1000 g = 2.2046 lbm

1 lbm = 16 oz = 0.45359 kg

1 slug = 32.174 lbm

Temperature Values

(T/K) = (T/ ºR) / 1.8

(T/K) = (T/ ºC) + 273.15

(T/ºC) = [(T/ ºF) – 32]/1.8

(T/ºR) = 1.8(T/K)

(T/ºR) = (T/ ºF) + 459.67

(T/ ºF) = 1.8(T/ ºC) + 32

Temperature Differences

(ΔT/ºR) = 1.8(ΔT / K)

(ΔT/ºR) = (ΔT/ºF)

(ΔT / K) = (ΔT/ºC)

Volume

1 m^3 = 1000 L = 10^6 cm^3 = 10^6 mL = 35.315 ft^3 = 264.17 gal

1 ft^3 = 1728 in^3 = 7.4805 gal = 0.028317 m^3

1 gal = 0.13368 ft^3 = 0.0037854 m^3

Volumetric Flow Rate

1 m^3/s = 35.315 ft^3/s = 264.17 gal/s

1 ft^3/s = 1.6990 m^3/min = 7.4805 gal/s = 448.83 gal/min

Force

1 N = 1 kg·m/s^2 = 0.22481 lbf

1 lbf = 1 slug·ft/s^2 = 32.174 lbm·ft/s^2 = 4.4482 N

Pressure

1 atm = 101.325 kPa = 1.01325 bar = 14.696 lbf/in^2

1 bar = 100 kPa = 10^5 Pa

1 Pa = 1 N/m^2 = 10^{-3} kPa

1 lbf/in^2 = 6.8947 kPa = 6894.7 N/m^2

[lbf/in^2 often abbreviated as “psi”]

Energy

1 J = 1 N·m

1 kJ = 1000 J = 737.56 ft·lbf = 0.94782 Btu

1 Btu = 1.0551 kJ = 778.17 ft·lbf

1 ft·lbf = 1.3558 J

Energy Transfer Rate

1 kW = 1 kJ/s = 737.56 ft·lbf/s = 1.3410 hp = 0.94782 Btu/s

1 Btu/s = 1.0551 kW = 1.4149 hp = 778.17 ft·lbf/s

1 hp = 550 ft·lbf/s = 0.74571 kW = 0.70679 Btu/s

Specific Energy

1 kJ/kg = 1000 m^2/s^2

1 Btu/lbm = 25037 ft^2/s^2

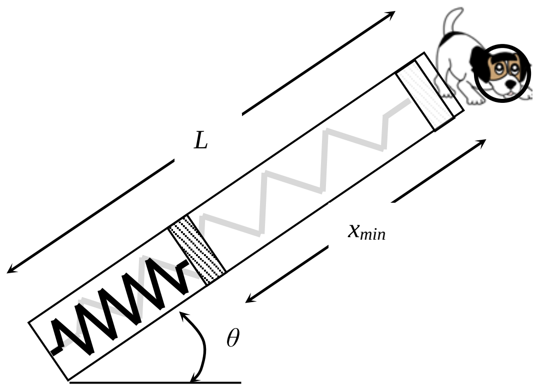
1 ft·lbf /lbm = 32.174 ft^2/s^2

Problem 1 (34 points)

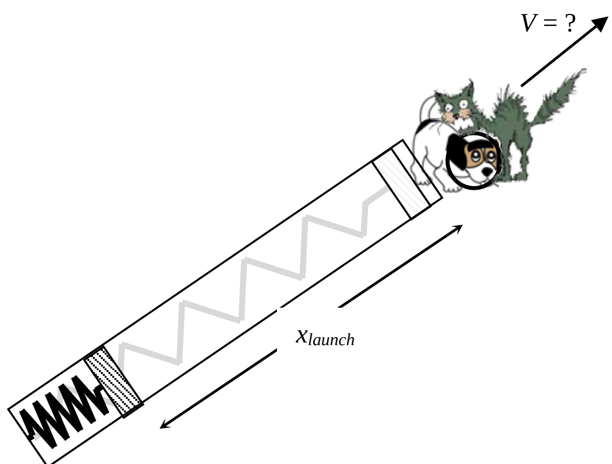
Not to be outdone by lowly chipmunks, dogs have decided to enter into space. Their launching device consists of a spring-loaded canon of barrel length L tilted at an angle θ as shown in the figure. The spring has a spring constant of k and is initially compressed. The spring is then allowed to completely uncompress, thereby shooting the astrodaug into space. The spring is completely uncompressed when it reaches the end of the barrel.

a) If the astrodaug has a mass m_{dog} and starts from rest, find the minimum compression in the spring, x_{min} so that the astrodaug just makes it out of the cannon at all.

b) The spring is compressed significantly more than in part a) to x_{launch} in order to ensure lift-off. Upon launch, however, an evil cat jumps in front of the cannon exit. If the evil cat has a mass of m_{cat} and sticks to the dog after launch, find the velocity of the astrodaug/cat as they exit the cannon.



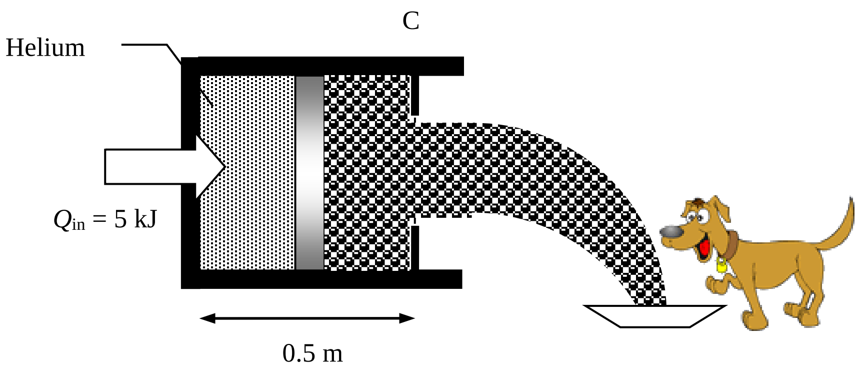
(a)



(b)

Problem 2 (33 points)

An automatic dog food dispenser uses thermal energy to expand helium (c_v = 3.12 kJ/kg-K, c_p = 5.19 kJ/kg-K) in a piston cylinder device. The cross-sectional area of the piston is 0.1 m^2, and the cylinder contains 4 g of helium initially at 100 kPa and 300 K. To dispense the food, 5 kJ of heat transfer is added to the helium. The dog food in the reservoir keeps the helium at constant pressure until the piston reaches the right-most boundary C, after which the piston is locked in place for the remaining of the heat addition.



a) Determine the initial volume of helium, in m^3.
b) Sketch the entire process on a P-V diagram and calculate the work in or out of the helium. Clearly indicate all relevant thermodynamic states and the process between them.
c) Determine the final temperature of helium at the end of the heating process, in K.

Problem 3 (33 points)

An innovative idea has been proposed to generate a high-speed water jet for a dog shower. A steady 10 kg/sec liquid water stream (c = 4.18 kJ/kg-K, ρ = 1000 kg/m^3) enters a pump at atmospheric conditions (101 kPa, 15^{o}C) and exits at 200 kPa, 20^{o}C. The high pressure water is then passed through a heat exchanger which raises its temperature to 30^{o}C. The heated stream is further fed into a nozzle which exhausts to the atmosphere at 101 kPa, 29^{o}C, at perfect dog drinking temperature and velocity.

a) Assume the pump operates adiabatically. Determine the power requirement of the pump, in kW.
b) Assume the pressure loss in the heat exchanger to be negligible. Determine the heat addition rate in the heat exchanger, in kW.
c) Determine the water stream velocity at the nozzle exit, in m/s.