

NAME \_\_\_\_\_ BOX NUMBER \_\_\_\_\_

Instructor / Section (please circle one):      Richards – Period 4      Adams – Period 4      Adams – Period 6

Problem 1 ( 30 ) \_\_\_\_\_

Problem 2 ( 25 ) \_\_\_\_\_

Problem 3 ( 25 ) \_\_\_\_\_

Problem 4 ( 20 ) \_\_\_\_\_

Total (100) \_\_\_\_\_

**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 and show a clear, logical progression from the basic principle(s). For FULL CREDIT, you must clearly show and label all energy transfers on a system diagram for your system.

- 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)/(90 min) ≈ 1 point/minute. That means a 10 point problem is not worth more than 10 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.)

USEFUL INFORMATION	SI	USCS
Ideal Gas Constant: $R_u$	= 8.314 kJ/(kmol-K)	= 1545 (ft-lbf)/(lbmol-°R)
		= 1.986 Btu/(lbmol-°R)
Standard Acceleration of Gravity: $g$	= 9.810 m/s <sup>2</sup>	= 32.174 ft/s <sup>2</sup>

## Length

$$1 \text{ ft} = 12 \text{ in} = 0.3048 \text{ m} = 1/3 \text{ yd}$$

$$1 \text{ m} = 100 \text{ cm} = 1000 \text{ mm} = 39.37 \text{ in} = 3.2808 \text{ ft}$$

$$1 \text{ mile} = 5280 \text{ ft} = 1609.3 \text{ m}$$

## Mass

$$1 \text{ kg} = 1000 \text{ g} = 2.2046 \text{ lbm}$$

$$1 \text{ lbm} = 16 \text{ oz} = 0.45359 \text{ kg}$$

$$1 \text{ slug} = 32.174 \text{ lbm}$$

## Temperature Values

$$(T/K) = (T/^{\circ}\text{R}) / 1.8$$

$$(T/K) = (T/^{\circ}\text{C}) + 273.15$$

$$(T/^{\circ}\text{C}) = [(T/^{\circ}\text{F}) - 32] / 1.8$$

$$(T/^{\circ}\text{R}) = 1.8(T/K)$$

$$(T/^{\circ}\text{R}) = (T/^{\circ}\text{F}) + 459.67$$

$$(T/^{\circ}\text{F}) = 1.8(T/^{\circ}\text{C}) + 32$$

## Temperature Differences

$$(\Delta T/^{\circ}\text{R}) = 1.8(\Delta T / K)$$

$$(\Delta T/^{\circ}\text{R}) = (\Delta T/^{\circ}\text{F})$$

$$(\Delta T / K) = (\Delta T/^{\circ}\text{C})$$

## Volume

$$1 \text{ m}^3 = 1000 \text{ L} = 10^6 \text{ cm}^3 = 10^6 \text{ mL} = 35.315 \text{ ft}^3 = 264.17 \text{ gal}$$

$$1 \text{ ft}^3 = 1728 \text{ in}^3 = 7.4805 \text{ gal} = 0.028317 \text{ m}^3$$

$$1 \text{ gal} = 0.13368 \text{ ft}^3 = 0.0037854 \text{ m}^3$$

## Volumetric Flow Rate

$$1 \text{ m}^3/\text{s} = 35.315 \text{ ft}^3/\text{s} = 264.17 \text{ gal/s}$$

$$1 \text{ ft}^3/\text{s} = 1.6990 \text{ m}^3/\text{min} = 7.4805 \text{ gal/s} = 448.83 \text{ gal/min}$$

## Force

$$1 \text{ N} = 1 \text{ kg}\cdot\text{m}/\text{s}^2 = 0.22481 \text{ lbf}$$

$$1 \text{ lbf} = 1 \text{ slug}\cdot\text{ft}/\text{s}^2 = 32.174 \text{ lbm}\cdot\text{ft}/\text{s}^2 = 4.4482 \text{ N}$$

## Pressure

$$1 \text{ atm} = 101.325 \text{ kPa} = 1.01325 \text{ bar} = 14.696 \text{ lbf}/\text{in}^2$$

$$1 \text{ bar} = 100 \text{ kPa} = 10^5 \text{ Pa}$$

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

$$1 \text{ lbf}/\text{in}^2 = 6.8947 \text{ kPa} = 6894.7 \text{ N}/\text{m}^2$$

[lbf/in<sup>2</sup> often abbreviated as “psi” ]

## Energy

$$1 \text{ J} = 1 \text{ N}\cdot\text{m}$$

$$1 \text{ kJ} = 1000 \text{ J} = 737.56 \text{ ft}\cdot\text{lbf} = 0.94782 \text{ Btu}$$

$$1 \text{ Btu} = 1.0551 \text{ kJ} = 778.17 \text{ ft}\cdot\text{lbf}$$

$$1 \text{ ft}\cdot\text{lbf} = 1.3558 \text{ J}$$

## Energy Transfer Rate

$$1 \text{ kW} = 1 \text{ kJ}/\text{s} = 737.56 \text{ ft}\cdot\text{lbf}/\text{s} = 1.3410 \text{ hp} = 0.94782 \text{ Btu}/\text{s}$$

$$1 \text{ Btu}/\text{s} = 1.0551 \text{ kW} = 1.4149 \text{ hp} = 778.17 \text{ ft}\cdot\text{lbf}/\text{s}$$

$$1 \text{ hp} = 550 \text{ ft}\cdot\text{lbf}/\text{s} = 0.74571 \text{ kW} = 0.70679 \text{ Btu}/\text{s}$$

## Specific Energy

$$1 \text{ kJ}/\text{kg} = 1000 \text{ m}^2/\text{s}^2$$

$$1 \text{ Btu}/\text{lbm} = 25037 \text{ ft}^2/\text{s}^2$$

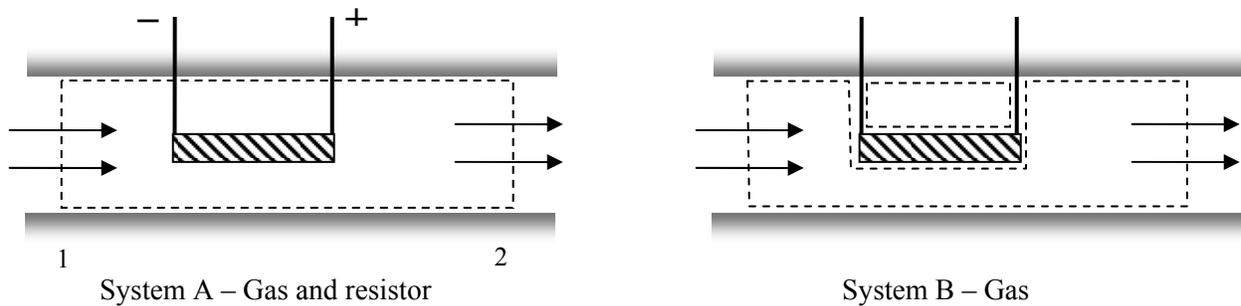
$$1 \text{ ft}\cdot\text{lbf}/\text{lbm} = 32.174 \text{ ft}^2/\text{s}^2$$

**Problem 1** ( 30 points )

(a) (8 points) Circle the correct answer:

- |      |       |   |
|------|-------|---|
| True | False | The change in internal energy of an ideal gas is a function of temperature only.                  |
| True | False | The change in specific internal energy of an ideal gas is a function of temperature only.         |
| True | False | The change in specific enthalpy of an ideal gas is a function of temperature only.                |
| True | False | The change in specific enthalpy of an incompressible substance is a function of temperature only. |
- 

(b) (6 points) A gas flows steadily through an insulated duct that contains an electric resistance heating element as shown in the figures below. (The only difference between the two figures is the system shown in the figures.)



What is the name of the energy transfer mechanism at the *non-flow boundaries* for System A?

What is the name of the energy transfer mechanism at the *non-flow boundaries* for System B?

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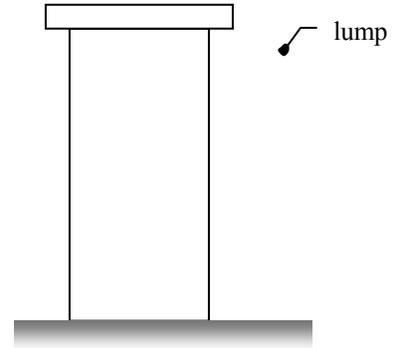
(c) (4 points) The output shaft of an automotive transmission has a torque of 1000 N-m and rotates at a speed of 1800 rpm (revolutions per minute). Determine the shaft power transmitted by the shaft.

**Problem 1 (continued)**

- (d) (10 points) A lump of lead falls 100 feet from the roof of a 10-story building and hits the pavement. The pavement is completely rigid and the lump is seriously deformed. The lump has a mass of 10 lbm.

Although the lead lump is seriously deformed, the density of the lead is constant and if necessary you may model the lead as an incompressible substance.

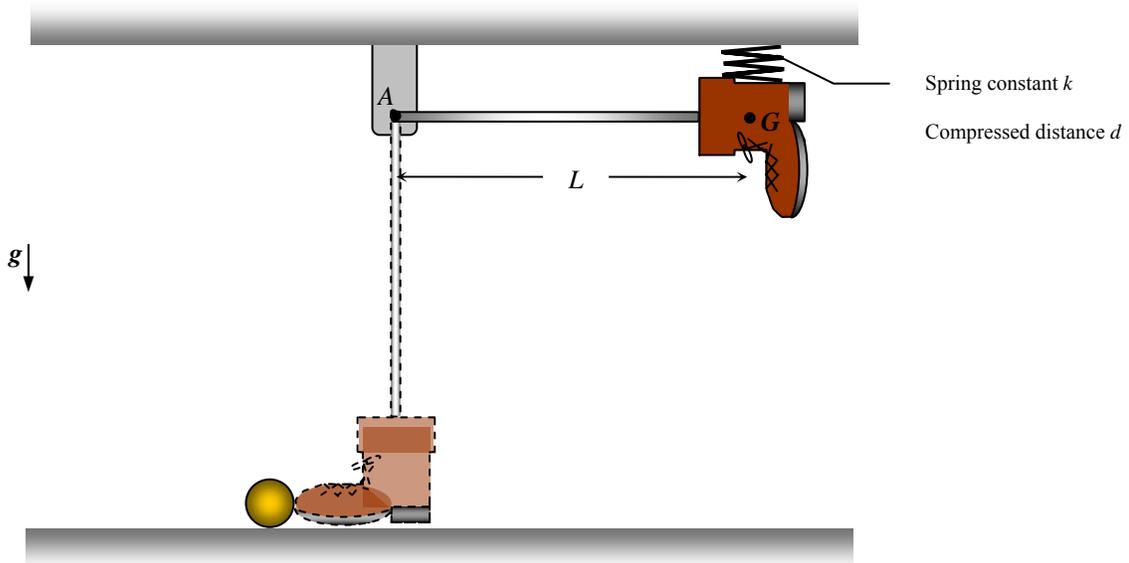
Determine the increase or decrease in the temperature of the lead if the process happens so quickly that heat transfer from the lead is negligible.



**Problem 3 ( 25 pts)**

A spring-loaded boot-on-a-stick kicks a marble as shown in the figure. Initially both the boot and marble are stationary. To load the device, the boot is swung up to the position shown and the uncompressed spring on the ceiling is compressed a distance  $d$ . The stationary boot is then released, swinging down and to the left before kicking the marble. The mass of the boot and marble are  $m_b$  and  $m_m$ , respectively, and the spring has a stiffness  $k$ . The stick of length  $L$  has negligible mass and is hinged to a frictionless pin at  $A$ .

- (a) Find an expression for the velocity of the boot just before it kicks the marble.
- (b) Assuming the boot and the marble stick together, find an expression for the velocity of the marble immediately after it has been kicked.
- (c) If the spring was initially compressed a distance  $d/3$  before the device was loaded, i.e. before it was compressed a distance  $d$  as described above, would the velocity found in part (a) increase, decrease or remain the same? Why? [A clear, concise, correct explanation without equations is acceptable.]



#### Problem 4 ( 25 points)

A typical cylinder for a Cummins Model H diesel engine is shown in the figure at right. Details of the compression process are shown below. The piston-cylinder volume contains air.

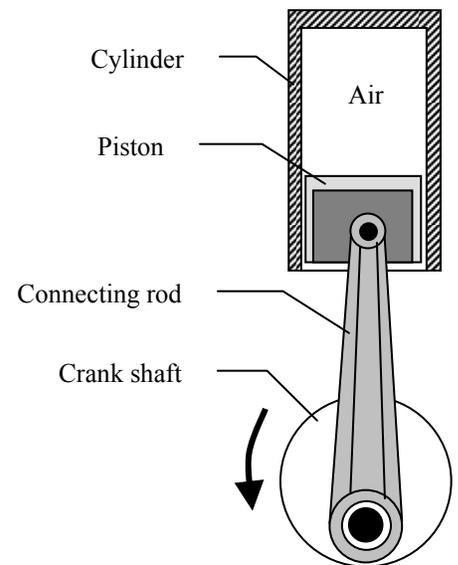
$$\text{State 1: } P_1 = 100 \text{ kPa, } T_1 = 320 \text{ K, } \Psi_1 = 300 \text{ cm}^3$$

$$1 \rightarrow 2: \text{ Compression process with } P\Psi^{1.3} = C$$

$$\text{State 2: } \Psi_2 = (1/16) \Psi_1$$

For modeling purposes, you may assume that the air can be modeled as an ideal gas with room-temperature specific heats.

- Determine the final pressure and temperature.
- Determine the heat transfer and work transfer of energy for the air during the compression process.
- Sketch the process on a  $P$ - $\Psi$  diagram. What if anything is the significance of the area under the process curve?



**Problem 5 ( 20 points)**

High-pressure hot water is mixed with  $0.20 \text{ ft}^3/\text{min}$  of high-pressure cold water in a showerhead as shown in order to produce a comfortable shower temperature of  $110^\circ\text{F}$ . The mixing process can be modeled as adiabatic with negligible kinetic and potential energies of the fluid streams. Assume liquid water can be modeled as an incompressible substance with room-temperature specific heats.

Find the required flow rate of hot water in  $\text{ft}^3/\text{min}$ .

