

Department of Physics
University of California, Berkeley

Mid-term Examination 1
Physics 7B, Sections 2 and 3

6:30 pm - 8:30 pm, October 4, 2005

Name: _____

SID No: _____

Discussion Section: _____

Name of TA: _____

Answer all five problems. Write clearly and explain your work. Partial credit will be given for incomplete solutions provided your logic is reasonable and clear. Cross out any parts that you don't want to be graded. Enclose your answers with boxes. **Express all numerical answers in SI units.** Answers with no explanation or disconnected comments will not be credited. If you obtain an answer that is questionable, explain why you think it is wrong.

Constants and Conversion factors

Avogadro number, N_A	6.022×10^{23}
Universal gas constant, R	$8.315 \text{ J}\cdot\text{mol}^{-1}\cdot\text{K}^{-1} = 1.99 \text{ cal}\cdot\text{mol}^{-1}\cdot\text{K}^{-1}$
Boltzmann constant, k	$1.381 \times 10^{-23} \text{ J}\cdot\text{K}^{-1}$
Stefan-Boltzmann constant, σ	$5.67 \times 10^{-8} \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-4}$
Acceleration due to gravity, g	$9.8 \text{ m}\cdot\text{s}^{-2}$
Specific heat of water	$1 \text{ kcal}\cdot\text{kg}^{-1}\cdot^\circ\text{C}^{-1}$
Heat of fusion of water	$80 \text{ kcal}\cdot\text{kg}^{-1}$
1 atm	$1.013 \times 10^5 \text{ N}\cdot\text{m}^{-2}$
1 kcal	$4.18 \times 10^3 \text{ J}$
1 BTU	1055 J
1 hp	746 W

1. A hollow plastic sphere at $20\text{ }^{\circ}\text{C}$ is found to have an inner radius of 1.925 cm and an outer radius of 3.142 cm at $20\text{ }^{\circ}\text{C}$. At this temperature, the density of the plastic is $1030\text{ kg}\cdot\text{m}^{-3}$. Then the sphere is dropped into a tank of hot water maintained at $100\text{ }^{\circ}\text{C}$ and no water is leaked into the sphere.

(a) [3 points] What is the overall density of the sphere at $20\text{ }^{\circ}\text{C}$? Ignore the mass of air inside the sphere.

(b) [12 points] After the sphere has reached thermal equilibrium with the hot water, what are the radii of the sphere? The average coefficient of thermal expansion of the plastic is 1×10^{-5} per $^{\circ}\text{C}$.

(c) [3 points] What is the overall density of the sphere after its temperature is at $100\text{ }^{\circ}\text{C}$? Ignore the mass of air inside the sphere.

(d) [2 points] Assuming the density of water at $100\text{ }^{\circ}\text{C}$ is about $998\text{ kg}\cdot\text{m}^{-3}$, does the sphere sink or float in the water initially, and after it reaches thermal equilibrium?

2 (a) [5 points] The average surface temperature of Mars is $-63\text{ }^{\circ}\text{C}$. What are the mean speeds of a hydrogen molecule and an oxygen molecule near the surface of Mars? Given the escape speed of Mars is 5.0 km/s , can the oxygen molecule eventually leave Mars?

(b) [5 points] In the LEP particle accelerator, the electrons go around a circular path of circumference 27 km in a chamber of 10^{-12} mm Hg pressure and 300 K temperature. What is the number density of the residual gas in the chamber? What would be the mean free path of the gas molecules under these conditions if the cross section is $2 \times 10^{-15}\text{ cm}^2$?

(c) Suppose the speed distribution of N particles is given by $n(v) = Cv$ for $0 < v < v_0$ and $n(v) = 0$ for $v > v_0$.

(i) [4 points] Determine the normalization constant C as a function of N and v_0 .

(ii) [6 points] Determine the mean speed and the root-mean-square speed of the particles.

3. A thin-wall cylindrical pipe is used to carry hot water at a temperature of $90\text{ }^{\circ}\text{C}$. The diameter of the pipe is 2.54 cm and it is wrapped around with a 2.54-cm-thick insulation. A section of the pipe, 5 m long, passes through a room at a temperature of $10\text{ }^{\circ}\text{C}$.

(a) [12 points] What is the rate of heat loss through the insulation? The thermal conductivity of the insulation is $0.05\text{ W}\cdot\text{m}^{-1}\text{K}^{-1}$.

(b) [2 points] What is the rate of change of entropy of the hot water? Treat the hot water as a reservoir of which the temperature is changed very little.

(c) [2 points] What is the rate of change of entropy of the insulation?

(d) [2 points] What is the rate of change of entropy of the room?

(e) [2 points] What is the rate of change of entropy of the universe? Is the second law of thermodynamics valid for this process?

4. During re-entry the space shuttle is slowed down by coming in at a large angle of attack, that is the angle between the wing and the direction of air flow. However, friction between the surface and the thin air in the upper atmosphere also generates a large amount of heat.

At the beginning of the re-entry the space shuttle travels at a speed of Mach 25, that is, 5.4 km/s at an altitude of 61 km. At this height, the temperature is 116 K, and the pressure is 10^{-4} atm.

(a) [10 points] The highest temperature of the silica tiles on the shuttle that is allowed to reach is 1568 K, whereas the aluminum frame shielded by the tiles is allowed to go up to 450 K. What is the amount of heat that can be dissipated from the surface of a 15 cm by 15 cm tile when all the materials reach their maximum allowed temperature? The thermal conductivity of silica at 1568 K and 10^{-4} atm is $0.073 \text{ BTU}\cdot\text{ft}^{-1}\cdot\text{hr}^{-1}\cdot\text{°F}^{-1}$. The thickness of the tile is 12.5 cm. The emissivity of the surface of the tile is 0.85.

(b) [5 points] What is the actual power dumped to the 15 cm by 15 cm tile at the beginning of the re-entry if the angle of attack is 40° ? The density of air at the altitude of 61 km is about $3 \times 10^{-4} \text{ kg}\cdot\text{m}^{-3}$.

5. A diesel engine employs four processes to complete a cycle. We shall model such an engine as a quasi-static reversible engine using an ideal gas. From an initial state a the gas is compressed adiabatically to state b . Then the gas is expanded at constant pressure to state c . During this transition an amount of heat Q_H is taken in. The process that goes from state c to state d is adiabatic. In the end of the cycle, heat of amount Q_L is ejected as exhaust during the isochoric process that goes from state d to state a .

(a) [5 points] Draw the cycle on a PV diagram with all the relevant quantities labelled clearly.

(b) [15 points] Determine the efficiency of this ideal engine in terms of the volumes of the states and the γ factor.

(c) [5 points] If the compression ratio, V_a/V_b , is 10, and the expansion ratio, V_a/V_c , is 5, calculate the ideal efficiency of the engine for an ideal diatomic gas. Here, V_i is the volume of the gas at state i .

End of Examination