Physics 7B Midterm 1 - Fall 2018
Professor R. Birgeneau

Total Points: 100 (5 Problems)

This exam is out of 100 points. Show all your work and take particular care to explain your steps. Partial credit will be given. Use symbols defined in problems and define any new symbols you introduce. If a problem requires that you obtain a numerical result, first write a symbolic answer and then plug in numbers. Label any drawings you make. **Good luck!**

Problem 1 (20 pts.)

(a) (10 pts.) A metal rod of mass 4 kg, specific heat 1000 J/ kg °C, initial length 20 cm, and initial temperature 40 °C is placed on a hot plate. Heat flows into the rod with a power of 400 W. After a time t, the metal rod has reached thermal equilibrium of 140 °C and now has a length of 20.08 cm. Determine the time t and the coefficient of linear expansion α.

(b) (10 pts.) A washer (annulus) of mass m_w with inner radius a_0 and outer radius b_0 is loosely pinned to a surface by a screw of mass m_s with screw head of radius $r_0 > a_0$. How much heat should we apply to the washer-screw combination if we wish to remove the washer without unscrewing the screw? Assume the washer and screw have specific heat capacities c_w and c_s, respectively, and assume the thermal expansion coefficients of the washer and screw are α_w and α_s, respectively, with $\alpha_w > \alpha_s$. Assume the change in temperature is small enough to warrant our use of linear thermal expansion.

Problem 2 (20 pts.)

Consider a monatomic gas of N particles at temperature T living in **three** isotropic spatial dimensions so that we label the position of a particle at a moment of time as a list of coodinates (x,y,z). We will also contain the gas of particles inside of a cube with side lengths l and volume $V = l^3$. Assume that the particles do not interact with each other and that they collide elastically with the cube walls.

(a) (3 pts.) How much time is there between collisions of a particle on a given wall?

(b) (5 pts.) Derive expression for the force F exerted on a given wall by the collision of gas particles.

(c) (6 pts.) Derive the equation of state of the gas that relates the temperature T, the volume V, and the force F.

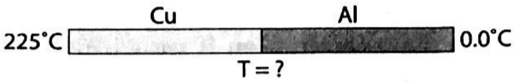
(d) (6 pts.) Now consider a gas of diatomic, linear molecules. Plot the specific heat as a function of temperature from low to high temperatures. Explain the physical reason and microscopic interpretation of any features of the plot (such as maxima, minima, plateaus, etc). Do not worry about giving an exact numerical value for the temperature of any particular feature of your plot.

Problem 3 (20 pts.)
A 0.5 kg chunk of ice at -10 °C is placed in 3.0 kg of water at 25 °C. Assume that $c_{water} = 4.0$ kJ/kg·K, $c_{ice} = 2.0$ kJ/kg·K, and $L_f = 300$ kJ/kg.

(a) (15 pts.) At what temperature and in what phase will the final mixture be?

(b) (5 pts.) Find the change in entropy of the ice-water system.

Problem 4 (15 pts.)
A copper rod and an aluminum rod of the same length and cross-sectional area are attached end to end (see diagram below). The copper end is placed in a furnace maintained at a constant temperature of 225 °C. The aluminum end is placed in an ice bath held at constant temperature of 0.0 °C. Calculate the temperature at the point where the two rods are joined. Assume that the thermal conductivity of aluminum and copper are given by $k_a = 5.0 \times 10^{-2}$ J/(s·m·°C) and $k_c = 10 \times 10^{-2}$ J/(s·m·°C), respectively.



Problem 5 (25 pts.)
An ideal gas of n moles of a molecule is used to run the Otto cycle, which operates between four points A→ B → C→ D →A, in that order, with temperatures T_A, T_B, T_C, and T_D such that

(i) Points B and C are connected by an isovolumetric process. Points A and D are also connected by an isovolumetric process.

(ii) Points C and D are connected by an adiabatic process. Points A and B are also connected by an adiabatic process.

Express your answers to the following in terms of the temperatures of each point as well as the volume V_b at point B and the volume V_a at point A, where $V_a > V_b$. Also assume that the gas has specific heat C_V and ratio of specific heats γ.

(a) (7 pts.) Draw a P-V diagram of the Otto cycle. Clearly label the points A, B, C, D on the diagram

(b) (7 pts.) Determine the heat that flows into/out of the cycle for each part of the cycle.

(c) (7 pts.) Find the change in entropy along each part of the cycle.

(d) (4 pts.) The efficiency of the Otto cycle is given by

$$e = 1 - \left(\frac{V_b}{V_a}\right)^{\gamma-1} \qquad (1)$$

Assuming that the cycle uses a diatomic molecule, find the efficiency when the cycle operates between volumes satisfying $V_a/V_b = 8.0$.

Formula Sheet: Physics 7B, Midterm 1

Thermodynamics

$$\Delta l = \alpha l_0 \Delta T$$

$$\Delta V = \beta V_0 \Delta T$$

$$Q = mc\Delta T = nC\Delta T$$

$$C_P - C_V = R = N_A k_B$$

$$\frac{dQ}{dt} = -kA\frac{dT}{dx}$$

$$e_{Carnot} = 1 - \frac{T_L}{T_H}$$

$$v_{rms} = \sqrt{\frac{3k_BT}{m}}$$ (for a monatomic gas)

$$e = \frac{W_{net}}{Q_{in}}$$

$$\Delta S = \int \frac{dQ}{T}$$ (For reversible processes)

$$dQ = TdS$$

$$\Delta S_{syst} + \Delta S_{env} > 0$$

$$\oint dS = 0$$
