

Department of Physics
University of California, Berkeley

Mid-term Examination 1
Physics 7B, Section 3

6:00 pm - 8:00 pm, 2 October 2008

Name:

SID No:

Discussion Section:

Name of TA:

Problem 1	
Problem 2	
Problem 3	
Problem 4	
Problem 5	

Score:

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	$80 \text{ kcal}\cdot\text{kg}^{-1}$	$333 \text{ kJ}\cdot\text{kg}^{-1}$
Heat of vaporization of water	$539 \text{ kcal}\cdot\text{kg}^{-1}$	$2260 \text{ kJ}\cdot\text{kg}^{-1}$
1 atm	$1.013 \times 10^5 \text{ N}\cdot\text{m}^{-2}$	
1 kcal	$4.18 \times 10^3 \text{ J}$	
1 hp	746 W	1 liter 10^3 cm^3

Some useful equations

$$\Delta L = \alpha L \Delta T \quad \Delta V = \beta V \Delta T$$

$$W = \int P dV$$

$$Q = mc \Delta T$$

$$Q = nC \Delta T, \text{ where } C = C_V \text{ or } C_P$$

$$PV^\gamma = \text{constant} \quad TV^{\gamma-1} = \text{constant} \quad \gamma = \frac{C_P}{C_V}$$

$$\frac{dN_v}{dv} = 4\pi N \left(\frac{m}{2\pi kT} \right)^{\frac{3}{2}} v^2 e^{-\frac{mv^2}{2kT}}; \quad v_{\text{most probable}} = \sqrt{\frac{2kT}{m}}$$

$$\bar{v} = \sqrt{\frac{8kT}{\pi m}} \quad v_{rms} = \sqrt{\frac{3kT}{m}} = \sqrt{\frac{3\rho}{P}}$$

$$\frac{dQ}{dt} = \sigma \epsilon A T^4 \quad \frac{dQ}{dt} = hA(T_s - T_a)$$

$$\frac{dQ}{dt} = -\kappa A \frac{dT}{dx}$$

1. [25 points] Short Questions

(a) [5 points] Circle T or F for True or False

T F (i) A carbon twelve, ^{12}C , atom has a mass of 12.0000 unified atomic mass units ($u = 1.6605 \times 10^{-27}$ kg).

T F (ii) There are at least 6.02×10^{23} molecules of nitrogen in a large breath (≤ 4 L) of air.

T F (iii) If the absolute temperature of a body increases by 1%, the rate at which it radiates energy increases by a factor of 5%.

T F (iv) When a system goes from equilibrium state 1 to state 2, the change in the internal energy is the same for all processes going between the two states.

T F (v) For any material that expands when heated, C_P is greater than C_V .

T F (vi) The specific heat of a monoatomic gas is greater than that of a polyatomic gas.

T F (vii) Entropy is a state variable.

T F (viii) The Carnot cycle drawn on an ST diagram, instead of PV diagram, is a rectangle.

T F (ix) The heat of vaporization is understood in the kinetic theory of gases as a result of the random motion of molecules.

T F (x) According to the principle of equipartition, energy is shared equally among the active degrees of freedom in an amount of $\frac{1}{2}kT$ in each on average.

(b) [5 points] Circle correct answer(s).

(i) Temperature is defined as:

- (A) A key state variable for describing a system in thermal equilibrium
- (B) An indication of “hotness”
- (C) A quantity measured with thermometers
- (D) A macroscopic coarse-grained variable measuring the mean random kinetic energy
- (E) All of the above
- (F) None of the above. They are all incorrect.

(ii) What is Brownian motion?

- (A) The irreducible motion of small objects suspended in a fluid being viewed through a powerful microscope.
- (B) The motion of small brown objects suspended in water due to their being heated by absorbing light used to illuminate them for viewing.
- (C) Motion of small particles suspended in water which was explained by Albert Einstein as being due to the random collisions water molecules on the small particles.
- (D) The motion of botanist Robert Brown 1827 when he looked at pollen grains
- (E) None of the above

(iii) Fanning yourself on a hot day cools you by

- (A) increasing the radiation rate from of your skin.
- (B) increasing the conductivity so heat flows out more readily.
- (C) increasing the mean free path of the air molecules.
- (D) increasing the evaporation of perspiration.
- (E) increasing the convection of heat from you skin.
- (F) None of the above.

(iv) The total length of the Golden Gate Bridge is 2,737 m. The temperature swing from a clear cool night to hot clear day is 50°C and the linear coefficient of expansion of the steel cables is about $\alpha = 12 \times 10^{-6}/^{\circ}\text{C}$ and its volume coefficient of expansion is about $\beta = 35 \times 10^{-6}/^{\circ}\text{C}$. How much does the length of the bridge change from night to day?

- (A) increase by 1.6 cm^2 .
- (B) increase by 4.8 cm^2 .
- (C) increase by 16 cm^2 .
- (D) increase by 48 cm^2
- (E) increase by 160 cm^2
- (F) increase by 480 cm^2

(v) The total weight of the Golden Gate Bridge (as built) is 811,500,000 kg. How much does the weight of the Bridge change in the 50°C temperature swing?

- (A) decreases by 4 kg
- (B) decreases by 2 kg
- (C) essentially no change
- (D) increases by 2 kg
- (E) increases by 4 kg

(c) [5 points] Circle correct answer

(i) A concrete highway is built of slabs 15m long with linear coefficient of expansion of $\alpha = 12 \times 10^{-6}/^{\circ}\text{C}$. How wide should the expansion cracks between the slabs be (at 15°C) to prevent buckling if the range of temperature is -30°C to 44°C ?

- (A) 0.13 m
- (B) 0.05 m
- (C) 0.013 m
- (D) 0.005 m
- (E) 0.001 m

(ii) An air bubble at the bottom of a lake 39.0 m deep has a volume of 1.16 cm^3 . If the temperature at the bottom is 5.4°C and at the top 18.5°C , what is the volume of the bubble just before it reaches the surface?

- (A) 1.11 cm^3
- (B) 1.16 cm^3
- (C) 4.0 cm^3
- (D) 5.8 cm^3
- (E) 18.9 cm^3

(iii) An iron cube floats in a bowl of liquid mercury at 0°C . If the temperature is raised to 25°C , will the cube float higher or lower in the mercury? The volume coefficient of Mercury is $180 \times 10^{-6}/^{\circ}\text{C}$ and for iron is $35 \times 10^{-6}/^{\circ}\text{C}$.

- (A) higher
- (B) same
- (C) lower
- (D) It depends on the shape of the iron cube, e.g. is it hollow?
- (E) There is not enough information to answer.

(iv) A square is cut out of a copper sheet. The square is heated uniformly. As a result, it turns into

- (A) a square with a larger area
- (B) a square with a smaller area
- (C) a rectangle with a larger area
- (D) a rectangle with a smaller area
- (E) If it has a hole in the middle, the square gets bigger but the area decreases
- (F) If it has a hole in the middle, it expands into a rectangle

(v) The Great Golden Bridge is just a long slab of pure gold with the opposite ends resting on the shores of the river. In the spring, when the air temperature is 100°C , the length of the bridge is 160.0 m. The value of α for gold is $14.2 \times 10^{-6}/^{\circ}\text{C}$. Compared to its length in the spring, by what amount does the length of the Great Golden Bridge decrease during the Teharian winter when the temperature hovers around -150°C ?

- (A) 1.36 m
- (B) 0.136 m
- (C) 0.0136 m
- (D) 0.00136 m
- (E) 5.68 m
- (F) 0.568m
- (G) 0.0568 m
- (H) 0.00568 m

(d) [5 points] Circle correct answer

(i) Calculate the rms speed of a nitrogen molecule at 10°C .

- (A) 100 m/s (B) 200 m/s (C) 300 m/s
(D) 400 m/s (E) 500 m/s (F) 600 m/s

(ii) The mean free path of Helium atoms at STP is measured to be about $25 \times 10^{-8}\text{m}$. Estimate the diameter of a Helium atom.

- (A) 0.9×10^{-10} m
(B) 1.8×10^{-10} m
(C) 3.6×10^{-10} m
(D) 7.2×10^{-10} m
(E) 14.4×10^{-10} m.

(iii) An ideal gas is expanded reversibly and isothermally a factor of two in volume. What is the work done by the gas in this process?

- (A) PV
(B) $nRT\ln(2)$
(C) $P_a V_a^\gamma (V_b^{1-\gamma} - V_a^{1-\gamma}) = P_a V_a - P_b V_b$
(D) $P(V_b - V_a)$
(E) none of the above

(iv) An ideal gas is expanded reversibly and isothermally a factor of two in volume. What is the entropy change of the gas in this process?

- (A) 0
(B) PV/T
(C) $nR\ln(2)$
(D) $(P_a V_a - P_b V_b)/T$
(E) $P(V_b - V_a)/T$
(F) All are correct

(v) An ideal gas is expanded reversibly and isothermally a factor of two in volume. What is the change in internal energy of the gas in this process?

- (A) PV
(B) $nRT\ln(2)$
(C) $P_a V_a^\gamma (V_b^{1-\gamma} - V_a^{1-\gamma}) = P_a V_a - P_b V_b$
(D) $P(V_b - V_a)$
(E) $nC_V \Delta T = 0$
(F) 0

(e) [5 points] Circle correct answer

(i) When two gases are mixed and in thermal equilibrium, the ratio of their molecules' mean translational kinetic energy is

- (A) one. The molecules have the same mean translational kinetic energy.
- (B) the ratio of their masses.
- (C) inverse ratio of the square root of their masses.
- (D) inverse ratio of their masses.
- (E) ratio of the square root of their masses.
- (F) It depends upon whether they are monatomic, diatomic, or polyatomic.

(ii) An inventor claims to have made a machine which takes in sea water, extracts salt and gold using the heat in the water to power the pumps and sends out cold contaminant free desalinated potable water along with gold. This violates which laws of Thermodynamics?

- (A) First Law (B) Second Law (C) Third Law (D) All laws
- (E) First and Second Law (F) Second and Third Law (G) First and Third Law

(iii) What is the change in entropy of 1 kg of ice at 0°C which melts to water at 0°C ?

- (A) 333 J/K (B) 3,330 J/K (C) 3.33×10^5 J/K
- (D) 122 J/K (E) 1,220 J/K (F) 12,200 J/K

(iv) Which of these gas laws is incorrectly stated?

- (A) Avogadro's Law: $V \propto n$ for constant temperature and pressure.
- (B) Diver's Law $P \propto n$ for constant temperature and volume.
- (C) Boyle's Law: $V \propto \frac{1}{P}$ at constant temperature and number.
- (D) Charles's Law: $V \propto T$ for constant pressure and number.
- (E) Gay-Lussac's law: $P \propto T$ for constant volume and number.
- (F) Ideal Gas Law: $PV = nRT = NkT$
- (G) Clausius equation of state: $P \left(\frac{V}{n} - b \right) = RT$
- (H) van der Waals equation of state: $\left(p + \frac{a}{(V/n)^2} \right) \left(\frac{V}{n} - b \right) = RT$
- (I) Dalton's law: two gases mixed together in equilibrium $P_1 + P_2 = P_{total} = (n_1 + n_2)RT/V$
- (J) All are correct

(v) One calorie of heat is added to a large volume of water at 300K. By what factor does the number of accessible states change?

- (A) 2×10^{20}
- (B) 1×10^{21}
- (C) 3×10^{22}
- (D) $e^{2 \times 10^{20}}$
- (E) $e^{10^{21}}$
- (F) $e^{3 \times 10^{21}}$

2. [20 points] **A Reversible Heat Engine Operating Between Varying Temperature Heat Baths:** Two identical blocks, A and B, with the same mass, m , and heat capacity, c , are at different initial temperatures, $T_A = 100^\circ\text{C}$ and $T_B = 0^\circ\text{C}$. Assume the two blocks are insulated so that there is no heat lost to the environment.

(a) [5 points] What is the final temperature of the two blocks, if they were allowed to come to equilibrium through heat transfer alone with no work extracted. (Replace the heat engine in the sketch below with a thermally conducting bar.) Show answer both symbolically and numerically.

(b) [5 points] Suppose instead the blocks are used as a heat source and a heat sink for a reversible heat engine. The heat engine operates until the temperature of the two blocks becomes identical, the final temperature T_f . Calculate the final temperature of the two blocks T_f . Show answer both symbolically and numerically.

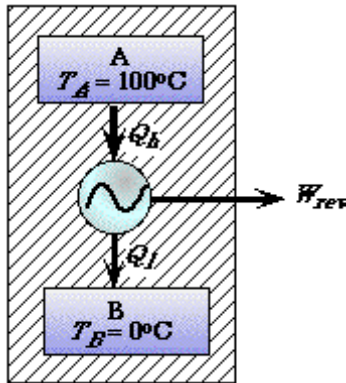


Figure 1: Initial Configuration for reversible heat engine.

(c) [5 points] Calculate symbolically the total work accomplished by this reversible heat engine. Evaluate for masses of 1000 kg and heat capacity of 1 kJ/kg/°C.

(d) [5 points] Determine the net thermal efficiency of this reversible heat engine. Compare it with the Carnot efficiency of a reversible heat engine operating between two fixed-temperature heat baths with the same two initial temperatures to show that the actual efficiency of this reversible engine is less than that. Show answer both symbolically and numerically.

3. [30 points] **Refrigerator Freezing Ice Problem:** The cooling compartment of a refrigerator operates at a low temperature of $T_L = -10.0^\circ\text{C}$, and exhausts heat into the air in the room at temperature $T_H = 21.0^\circ\text{C}$. The motor of the refrigerator requires $P = 3/4$ horsepower of useful work to operate the refrigeration cycle. Give a **symbolic answer** in addition to a **numeric answer** for each portion of the question.

(a) [4 points] What is the maximum possible coefficient of performance of this refrigerator?

(b) [3 points] What is the rate, \dot{Q}_L , that heat is taken out of the refrigerator, if it operates at a fraction $f = 43.0\%$ of its maximum coefficient of performance?

(c) [4 points] What is the rate, \dot{Q}_H , in which heats from refrigerator is exhausted into the environment each second, if it operates at $f = 43.0\%$ of its maximum coefficient of performance?

(d) [4 points] How long would it take to cool and freeze 4.20 kg of water at 18.0°C to ice at 0°C when placed in the refrigerator?

(e) [10 points] What is the change in entropy of the ice, the air in the room, and the minimum change in the entropy of the universe during the freezing process?

(f) [5 points] What is the entropy change of the universe per cycle, if the refrigerator worked at the maximum possible coefficient of performance found in part (a)? Why? How much faster would it be from putting the water in until it freezes to ice? Give your answer as a fraction $t_{ideal}/t_{actual} = t_{100\%}/t_{43\%}$.

4. [25 points] **Heat Conduction Problem** Two square bars that have a cross-sectional area of $A = 25 \text{ cm}^2$ are joined end-to-end. One bar has length $L_{Cu} = 26.0 \text{ cm}$ and is made of copper (thermal conductivity $k_{Cu} = 400 \text{ W/m}\cdot\text{C}$). The other bar has length $L_{Al} = 33.0 \text{ cm}$ and is made of aluminum (thermal conductivity $k_{Al} = 240 \text{ W/m}\cdot\text{C}$). The copper end is placed in boiling water (temperature $T_h = 100^\circ\text{C}$) and the aluminum end is placed in an ice-water mixture (temperature $T_c = 0^\circ\text{C}$) and the system is allowed to come to a steady state. If The sides of the bars are well insulated so that no heat is lost out the sides of the bars. In the following parts, please give both a **symbolic answer** and a **numeric answer**!

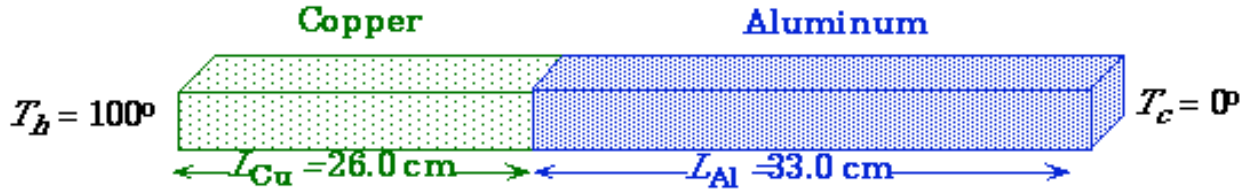


Figure 2: Configuration for conducting bars.

(a) [5 points] What is the temperature at their interface where they are joined?

(b) [5 points] What would the length of the aluminum bar have to be in order for the temperature of the interface to be exactly 50°C ?

(c) [5 points] What is the rate of heat flow through the copper bar, \dot{Q}_{Cu} ? What is the rate of heat flow through the aluminum bar, \dot{Q}_{Al} ?

(d) [5 points] What is the rate of entropy production, \dot{S} , for this process? (Give symbolic answer and evaluate.)

(e) [5 points] If all the linear dimensions of the bars were increased by a factor of two, how would the heat flow change?

5. [30 points] **Gas and Climate Issues Problem:**

(a) [5 points] The burning of gasoline in a car releases about $3.0 \cdot 10^4$ (kcal/gal). If a car averages 45 km/gal when driving 95 km/hr, which requires 25 horsepower, what is the efficiency of the engine under those conditions?

(b) [5 points] Suppose the gasoline has the typical chemical composition of C_8H_{18} and burns completely into CO_2 and H_2O . ($C_8H_{18} + 12.5O_2 \rightarrow 8CO_2 + 9H_2O$) What mass rate and mole rate of production is there of CO_2 and H_2O . Assume that a gallon of gasoline corresponds to 2.8 kg.

(c) [5 points] What will be the volume given off per hour of the two gases (CO_2 and H_2O) when the gases are at an ambient temperature of $20^\circ C$ and one atmosphere of pressure?

(d) [5 points] Water vapor and CO_2 added to the atmosphere increase the emissivity. CO_2 increases the emissivity in the infrared (where the Earth's thermal radiation peaks) according to $\epsilon_{\text{CO}_2} = A + B * \ln(C/C_0)$, where C is the increased atmospheric density of CO_2 compared to the pre-driving density of CO_2 called C_0 . For this problem assume that $A = 0.05$, $B = 0.04$, and $C_0 = 300\text{ppmv}$ (parts per million by volume) from pre-1960. It is 383 ppmv now. How much has the infrared emissivity of the atmosphere increased due to the CO_2 increase between 1960 and now? What would be the corresponding temperature rise for the Earth?

(e) [2 points] The Greenhouse Effect is more difficult to calculate when including water vapor because there is positive feedback. A temperature rise of the ground, and especially of oceans and lakes causes water vapor in the atmosphere to increase. (So also is reflecting cloud cover.) For a 1°C rise from 14°C by how much would the water vapor fraction rise? The saturated vapor pressure of water at 14°C and 15°C are about $1.6 \times 10^3\text{Pa}$ ($= \text{N/m}^2$) and $1.71 \times 10^3\text{Pa}$ ($= \text{N/m}^2$) respectively and an average relative humidity for the earth is about 50%. What would be fractional content of the atmosphere in water vapor by volume?

(f) [5 points] Why does the water vapor partial pressure rise increasingly rapidly with temperature? See attached figure and provide a rough physical argument/reason and an approximate formula.

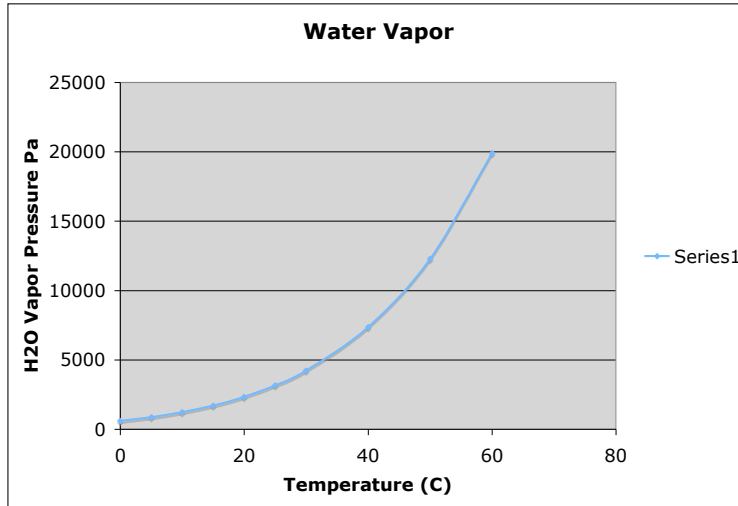


Figure 3: Water Vapor Partial Pressure Versus Temperature.

(g) [3 points] At the same temperature, a column of dry air will be denser or heavier than a column of air containing any water vapor. Thus, any volume of dry air will sink if placed in a larger volume of moist air. Also, a volume of moist air will rise or be buoyant if placed in a larger region of dry air. As the temperature rises the proportion water vapor in the air increases, its buoyancy will become larger. This increase in buoyancy can have a significant atmospheric impact, giving rise to powerful, moisture rich, upward air currents when the air temperature and sea temperature reaches 25°C or above. This phenomenon provides a significant motivating force for cyclonic and anticyclonic weather systems (tornados and hurricanes).

What is the difference in density at 15°C ($1.71 \times 10^3 \text{Pa}$) between dry and saturated air? How about at 25°C (3170 Pa), what is the difference in density?