

Department of Physics
University of California, Berkeley

Mid-term Examination 1
Physics 7B, Section 1

6:00 pm - 8:00 pm, 4 October 2006

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	$1 \text{ kcal}\cdot\text{kg}^{-1}\cdot^\circ\text{C}^{-1}$	ice $0.5 \text{ kcal}\cdot\text{kg}^{-1}\cdot^\circ\text{C}^{-1}$
Heat of fusion of water	$80 \text{ kcal}\cdot\text{kg}^{-1}$	
Heat of vaporization of water	$539 \text{ kcal}\cdot\text{kg}^{-1}$	
1 atm	$1.013 \times 10^5 \text{ N}\cdot\text{m}^{-2}$	
1 kcal	$4.18 \times 10^3 \text{ J}$	
1 hp	746 W	1 liter 10^3 cm^3

Some useful equations

$$\Delta L = \alpha L \Delta T$$

$$W = \int p dV$$

$$Q = mc\Delta T$$

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

$$\bar{v} = \sqrt{\frac{8kT}{\pi m}}$$

$$\frac{dN_v}{dv} = 4\pi N \left(\frac{m}{2\pi kT}\right)^{\frac{3}{2}} v^2 e^{-\frac{mv^2}{2kT}}$$

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

$$\frac{dQ}{dt} = \sigma \epsilon A T^4$$

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

1. [27 points] Short Questions

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

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

T F (ii) A macroscopic description is given in terms of quantities that are an average over the microscopic details and are called state variables. Pressure and Temperature are state variables.

T F (iii) The heat capacity of a body is the amount of heat that it can store at a given temperature.

T F (iv) Even though two bodies are in thermal equilibrium with a third, that does not mean that they are in thermal equilibrium with each other.

T F (v) The mean free path for air molecules at standard temperature and pressure (STP) is about 10^{-7} m.

T F (vi) The internal energy of a given amount of an ideal gas at equilibrium depends only on its absolute temperature.

T F (vii) 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.

T F (viii) If the absolute temperature of a body triples, the rate at which it radiates energy increases by a factor of 9.

T F (ix) For a solid the mean distance between atoms is 2×10^{-10} m.

T F (x) Diffusion is described in the kinetic theory of gases as a result of the random motion of molecules.

(b) [5 points] Circle correct answer

(i) A concrete highway is built of slabs 12 m long at 20°C . How wide should the expansion cracks be between the slabs at 20°C to prevent buckling, if the temperature range is -30°C to $+50^{\circ}\text{C}$? For concrete $\alpha = 12 \times 10^{-6}/^{\circ}\text{C}$

- (A) 4.3×10^{-5} m (B) 4.3×10^{-4} m
(C) 4.3×10^{-3} m (D) 4.3×10^{-2} m
(E) 4.3×10^{-1} m (F) 4.3 m

(ii) An inventor claims he has produced a motor that takes heat from sea water, generates electricity, and rejects waste heat to warm buildings. He is seeking investors. You chose not to invest because this violates

- (A) the First Law of Thermodynamics.
(B) the Second Law of Thermodynamics.
(C) the Third Law of Thermodynamics.
(D) the First and Second Law of Thermodynamics.
(E) the Second and Third Law of Thermodynamics.

(iii) Oceans as Global Thermometer: Various climate modelers predict that the Temperature of the Earth will rise between 1.5 and 5°C in the next 30 years. Water has a volume coefficient of expansion of $2.1 \times 10^{-4}/^{\circ}\text{C}$. Assume the volume coefficient for earth is $0.1 \times 10^{-4}/^{\circ}\text{C}$. The mean depth of the Ocean is about 12,000 ft (3700 m). How much will the level of the Ocean rise?

- (A) no change at all
(B) 1 to 4 feet (0.3 to 1.3 m)
(C) 3 to 12 feet (1 to 4 m)
(D) 0.3 to 1.2 feet (0.1 to 0.4 m)
(E) 300 feet (100 m)

(iv) You are feeling feverish and take your temperature with a metric medical thermometer and find your temperature is 39°C . What is your temperature in Fahrenheit and are you ill?

- (A) 98.6°F and you are normal (B) 99°F and you have a very slight fever.
(C) 99.5°F and are a little ill. (D) 100°F and you are ill.
(E) 101°F and you are fairly sick. (F) 102°F and you are quite sick
(G) 103°F and you are very sick (H) 104°F and you are critically ill

(v) The fog blows in across the Bay and quickly (no time for heat to flow) up to the room of this exam an altitude of about 200 m. If the temperature on the Bay is 22°C and the pressure is $10^5 \text{N}/\text{m}^2$ and the density is roughly $1 \text{kg}/\text{m}^3$. What will the difference in its pressure and temperature in the room? ($\Delta T = T_{\text{room}} - T_{\text{bay}}$)

- (A) Pressure is the same and temperature is same.
(B) Pressure difference about $2000 \text{N}/\text{m}^2$ lower and temperature 6°C higher
(C) Pressure difference about $2000 \text{N}/\text{m}^2$ lower and temperature 6°C lower
(D) Pressure difference about $2000 \text{N}/\text{m}^2$ lower and temperature 1.7°C lower
(E) Pressure difference about $2000 \text{N}/\text{m}^2$ lower and temperature 0.6°C lower
(F) Pressure difference about $200 \text{N}/\text{m}^2$ lower and temperature 0.6°C lower
(G) Pressure difference about $200 \text{N}/\text{m}^2$ lower and temperature 1.6°C lower

(c) [5 points] Circle correct answer

(i) What is the factor by which the number of accessible states changes when 1 kg of water temperature increases 1°C from 27°C ?

- (A) 10^{24}
- (B) 10^{25}
- (C) $10^{4.3849 \times 10^{23}}$
- (D) $10^{4.3849 \times 10^{24}}$
- (E) $10^{4.3849 \times 10^{25}}$
- (F) $10^{4.3849 \times 10^{26}}$

(ii) What is the mean speed of air molecules at STP?

- (A) 0.5 m/s
- (B) 5 m/s.
- (C) 50 m/s
- (D) 500 m/s.
- (E) 5000 m/s.

(iii) The critical temperature of a real gas is

(A) the temperature at and above which vapor of the substance cannot be liquefied, no matter how much pressure is applied

(B) the temperature of the PV isotherm curve goes horizontal and goes through the critical point.

(C) both (A) and (B).

(D) the division between gas and vapor

(E) All of the above.

(iv) The mean time between collisions of air molecules at standard temperature and pressure is roughly

- (A) 10^{-25} sec
- (B) 10^{-20} sec
- (C) 10^{-15} sec.
- (D) 10^{-10} sec.
- (E) 10^{-5} sec

(v) What is the triple point?

(A) It is the critical point.

(B) The point at which liquid can no longer exist.

(C) The point at which vapor can no longer exist

(D) The point where solid, liquid, and vapor can coexist in equilibrium

(E) The point where solid, liquid, and gas can coexist in equilibrium

(F) The point where gas, vapor, and liquid can coexist in equilibrium

- (d) [5 points] Circle correct answer
- (i) The van der Waals equation of state is
- (A) a simple correction to the ideal gas law taking into account the finite volume of the molecules
 - (B) a simple correction to the ideal gas law taking into account the small attractive forces of the molecules on each other
 - (C) $P \left(\frac{V}{n} - b \right) = RT$
 - (D) $\left(P + \frac{a}{(V/n)^2} \right) \left(\frac{V}{n} - b \right) = RT$
 - (E) $P_1 + P_2 = P_{total} = (n_1 + n_2)RT/V$.
- (ii) What is the internal energy U of a monoatomic ideal gas?
- (A) $U = \frac{1}{2} Nk_B T = \frac{1}{2} nRT$
 - (B) $U = \frac{3}{2} Nk_B T = \frac{3}{2} nRT$
 - (C) $U = \frac{5}{2} Nk_B T = \frac{5}{2} nRT$
 - (D) $U = \frac{6}{2} Nk_B T = 3nRT$
 - (E) $U = \frac{7}{2} Nk_B T = \frac{7}{2} nRT$
- (iii) Which of these is **not** a latent heat?
- (A) heat of fusion.
 - (B) heat of vaporization.
 - (C) heat of phase change.
 - (D) heat of friction
 - (E) none of the above
- (iv) What is **not** a statement of the First Law of Thermodynamics?
- (A) Energy is conserved.
 - (B) $dU = dQ - dW$
 - (C) The change in a system's internal energy is the difference between the heat added to the system and the work done by the system.
 - (D) Heat is a transfer of energy due to a difference in temperature.
- (v) Which of these is **not** true for free expansion of a gas. I.e. The gas is initially in only one side of the container and allowed to expand without interference or resistance.
- (A) No work is done in free expansion.
 - (B) Free expansion is adiabatic.
 - (C) The internal energy of the gas remains constant.
 - (D) Free expansion is a good example of a non-equilibrium process..
 - (E) The entropy of the gas is unchanged in free expansion.

- (f) [7 points] Circle correct answer: The Human Heat Engine
- (i) [1 points] What is not a significant method by which the body rids itself of heat?
- (A) Conduction - The thermal conductivity of human flesh is about 0.2 J/s/ m^2 .
 - (B) Convection - blood flow
 - (C) Convection - air flow, e.g. fan
 - (D) Evaporation - perspire and transpire about 0.5 kg of water per day
 - (E) Radiation - thermal blackbody
 - (F) Cold drinks
- (ii) [1 points] Suppose a human could live for two hours (120 minutes) unclothed in air at 45° F . How long could he live in water at 45° F ? Water has 23 times the thermal conductivity that air has.
- (A) 2760 minutes
 - (B) 276 minutes
 - (C) 120 minutes
 - (D) 52 minutes
 - (E) 5.2 minutes
- (iii) Why do people become "flushed" when overheated?
- (A) heat makes your skin turn redish
 - (B) perspiration makes the skin look splotchy and red
 - (C) People are embarrassed when hot and blush.
 - (D) The body's circulation system opens blood vessels near the skin's surface to improve the convection of heat by blood from the internal portion of the body to the skin.
 - (E) Hotter skin radiates in the red the way steel glows when it first gets hot.
- (iv) How much heat power does the human body radiate? Assume a body temperature = 37° C and estimate surface area $A = 1.5 \text{ m}^2$ and emissivity $e = 0.70$.
- (A) 550 watts
 - (B) 440 watts
 - (C) 330 watts
 - (D) 220 watts
 - (E) 110 watts
 - (F) 55 watts
 - (G) 44 watts
 - (H) 33 watts
 - (I) 22 watts
- (v) On a very cold day the net heat loss of a human is 219 Joules per second. How many food Calories of energy will be lost in one hour?
- (A) 200,000 Calories
 - (B) 20,000 Calories
 - (C) 2000 Calories
 - (D) 200 Calories
 - (E) 20 Calories

(vi) Each person has chromosomes holding about 30,000 genes with about 5 billion base pairs. Each base pair holds 2 bits of information: A, T, C, or G. That's 10 billion bits, or 10 gigabytes.

Let's contrast this with the amount of mental information you learn and store in your brain over your lifetime. Psychological experiments have estimated [T.K.Landauer: "How much do people remember", *Cognitive Sci.* 10,4 (1986) 477-493; 12,2 (1988) 293-297] that you remember about 2 bits per second and end up holding somewhere between 0.5 and 3.4 gigabits of memory. Typically 2.5 gigabits.

What is the relative entropy increase during the lifetime to peak memory? How does that compare to the entropy increase per second from the regular human metabolism of about 70 watts or the stored entropy in a 50 kgm body?

- (A) 21.6 vs 70 or 200 J/K
- (B) $21.6k_B$ vs 70 J/K or 200,000 J/K
- (C) $2.5 \times 10^9 k_B$ vs 70 J/K or 200,000 J/K
- (D) 2.5×10^9 J/K vs 70 J/K or 200,000 J/K

(E) The entropy increases by a very large because of failure to remember most information and that exceeds the increase by heat loss and other stored entropy.

(vii) The human body is exceptionally efficient at extracting energy from food. Feces retain only about 5 per cent of the chemical energy originally present in the food consumed. Most of this energy is going into basic maintenance or metabolic work. Efficiencies are lower when we look at the energy consumed that goes into mechanical work. Cycling is one of the most efficient activities that humans can engage in. For a trained cyclist, efficiencies approach 20 per cent with mechanical work being generated at a rate of 370 W compared to a metabolic work of 1850 W. Cars are notoriously wasteful in comparison. Gasoline has an energy content of 477 MJ/kg and a density of 680 kg/m³. If a car can travel 8500 km per m³ of gasoline (8.5 km per liter or 15 mpg) the car will use 40 times more energy over the same distance. Muscle contractions could be up to 50 per cent efficient. What is the minimum effective temperature that food energy is being converted into heat energy, if the human body is a heat engine?

- (A) 1000 K
- (B) 500 K
- (C) 375 K
- (D) 310 K
- (E) 240 K

2. [20 points] An air bubble at the bottom of a lake 37.0-m deep has a volume of 1.00 cm^3 . If the temperature at the bottom is 5.5°C and at the top 21.0°C .

Give formulae and then evaluate.

(a) [15 points] what is the volume of the bubble just before it reaches the surface?

(b) [5 points] Draw and label a P-V diagram showing the trajectory of the bubble from the bottom of the lake to the surface. Show two isothermals with the temperature at the bottom and top of the lake for reference along with marking the bottom and top volumes and pressures.

3. [28 points] Suppose 2.00 mol of an ideal diatomic gas of volume $V_1 = 3.50m^3$ at $T_1 = 300K$ is allowed to expand isothermally to volume $V_2 = 7.00m^3$ at $T_2 = 300 K$.
- (a) [4 points] How much work is done by the gas?

(b) [4 points] How much heat is added to the gas?

(c) [4 points] What is the change in internal energy of the gas?

(d) [4 points] The gas is compressed from $V_2 = 7.00m^3$ to $V_1 = 3.50m^3$ at constant pressure. How much work is done by the gas?

(e) [4 points] Now the temperature is raised to $T_1 = 300$ K at constant volume $V_1 = 3.50m^3$. How much work is done? What is the change in internal energy?

(f) [4 points] For the full cycle what is the net work done? Show this on a PV diagram.

(g) [4 points] What is the efficiency of the process? How does it compare to Carnot efficiency of a Carnot cycle between the highest and lowest temperature?

4. [25 points] For a modern power plant, the pressure of the steam can be as high as 70 atmospheres at 300°C (573 K); the exhaust is at one atmosphere and perhaps 40°C (313 K).

(a) [1 points] For such a power plant, the maximum thermodynamic efficiency is?

(b) [2 points] For such an ideal power plant, suppose that the rate of waste heat out is $1.2\text{GW} = 1.2 \times 10^9 \text{watts}$, what is the rate of input heat? What is the rate of entropy production?

(c) [2 points] For an actual engine, which necessarily runs irreversibly, the actual efficiency, $e = 1/3$, is less than the maximum efficiency. If the output electric power is $1\text{GW} = 10^9 \text{watts}$. What are the rates of waste heat and entropy production?

The temperature difference between the outside and inside of your house is 5°C and you need 1 kilowatt of heat flow to keep your bathroom at your ideal temperature of 22°C .

(d) [3 points] If you use an ideal heat pump to get this heat flow, what electric input power do you need? What total input energy is needed at the power plant (33% efficiency) to produce this? What is the rate of total entropy production including the power plant?

(e) [2 points] If you use an electric resistance (turns electric power to heat irreversibly) heater, what total input energy is needed at the power plant (33% efficiency) to produce this? What the rate of total entropy production including the power plant?

(f) [2 points] What power do you need if you burn the fuel in a space heater in the bathroom, if one third the heat goes out the vent required to prevent CO build up? What is the rate of total entropy production assuming the combustion temperature is 300°C ?

(g) [3 points] Draw and label a PV diagram for the actual power plant . Show the beginning temperature and pressure and ending temperature and pressure as circled points on the PV diagram. To be specific consider one mole of steam. Sketch the following curves starting from the initial temperature and pressure: (i) isothermal expansion, (ii) adiabatic, (iii) estimated actual path.

5. [20 points] A refrigerator absorbs heat from the freezer compartment at a temperature of -17°C and exhausts it into the room at 25°C with an actual coefficient of performance of $\text{CP} = 5$.

(a) [5 points] How much work must be done by the refrigerator to change 0.50 kg of water put in at 25°C into ice at -17°C . What would be the coefficient of performance if it were a "Carnot" (ideal) refrigerator? How much work would be required then?

(b) [5 points] If the compressor output is 200 watts, what minimum time is needed to take 0.50 kg of 25°C water and freeze it at 0°C ?

(c) [5 points] Each time the door to the freezer is opened five moles of air (diatomic gas) at 25°C enters the refrigerator displacing the same amount of cold air (0°) and must be cooled to 0°C . How much heat must be removed? How much work is done by the ideal refrigerator each time the freezer is opened and then closed? If typically the time between opening the refrigerator door is an hour, what is the power used?

(d) [5 points] The freezer compartment is surrounded by foam insulation with $k_{\text{foam}} = 0.025 \text{ J}/(\text{s m } ^{\circ}\text{C})$ which has a area of 6 m^2 and thickness of 4 cm . What is the heat load in watts from the 25°C to the 0°C refrigerator? If the motor for the cooling unit should run no more than 15 per cent of the time what is the minimum power requirements for the motor?