Physics 340 **Midterm # 1 - Solutions** **27-September-00**

Name (please print):____

Student ID #: – –

This is a closed book exam. You may use a calculator.
A sheet with useful constants and equations is appended at the end.

There are 10 short problems in this exam. Each is directed at a single concept which we have covered. This is a 50 minute exam, so you have 5 minutes per problem. If you encounter one which you don't know how to approach, skip over it and make sure you have time to do all those which you know how to do.

Part I:
Questions 1 - 8 are multiple choice with no partial credit. Select the letter corresponding to the one best answer and write it under the question number in the answer table at the bottom of this page. Check the answer table carefully, as only it will be examined.

Part II:
For questions 9 and 10, partial credit will be awarded as appropriate. Show all the work needed to get your answer. Use blank areas (including backs of pages) for calculations.

	Points	**Score**
Part I	**72**	
Part II	**28**	

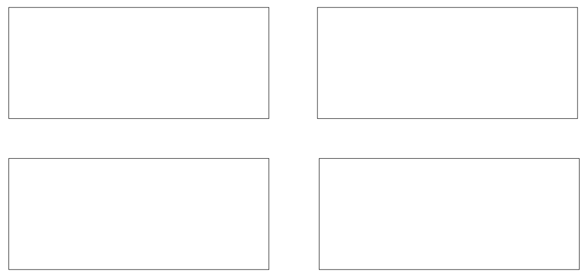
Total: ____________________

ANSWER TABLE for Part I: Below each question number, insert the letter corresponding to the one best answer.

Question	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Your answer	**A**	**C**	**C**	**B**	**E**	**B**	**D**	**A**

Part I (72 pts total) NO PARTIAL CREDIT – TRANSFER YOUR ANSWERS TO THE ANSWER TABLE

1. (9 pts) The concrete sections of a road are designed to be 25m long and 5m wide and will be built at a temperature of 10°C. How much space should be left between the ends of the sections to prevent "buckling" of the road at 50°C.
(The thermal expansion coefficient of concrete is $12 \cdot 10^{-6}/°C$)



(A) 1.2 cm (B) 12 cm (C) 12 m (D) 1.2 mm (E) 0 cm

$$\Delta L \; = \; L\,\alpha\,\Delta T \; = \; 25 \text{ m} \cdot 12 \cdot 10^{-6}/°\text{C} \cdot 40\ °\text{C} \; = \; 1.2 \text{ cm}$$

2. (9 pts) How much heat is required to change 250g of ice with an initial temperature of −10°C into water with a final temperature of +10°C?
(The specific heat of ice is 2220 J/kg · K)

(A) 58 kJ (B) 26 kJ **(C) 99 kJ** (D) 2.6 kJ (E) 580 kJ

Solid: $\Delta Q \; = \; c_s\, m\, \Delta T \; = \; 2220 \text{ J/kgK} \cdot 0.25 \text{ kg} \cdot 10 \text{ K} \; = \; 5.55 \text{ kJ}$
Fusion: $\Delta Q \; = \; c_F\, m \; = \; 333 \text{ kJ/kg} \cdot 0.25 \text{ kg} \; = \; 83.25 \text{ kJ}$
Liquid: $\Delta Q \; = \; c_l\, m\, \Delta T \; = \; 4190 \text{ J/kgK} \cdot 0.25 \text{ kg} \cdot 10 \text{ K} \; = \; 10.48 \text{ kJ}$

Total: $\Delta Q \; = \; 99.28 \text{ kJ}$

3. (9 pts) A tree house in the shape of a cube with side 2.0m is built out of 2.0cm thick white pine with a thermal conductivity of $k = 0.11\text{W/m}\cdot\text{K}$. What is the heat flow out of this tree house if its interior is maintained at +20°C while the outside temperature is +5°C? (Assume that any windows and doorways are shuttered with the 2.0cm thick white pine.)

(A) 264 W (B) 330 W **(C) 1980 W** (D) 2640 W (E) 3300 W

$$H = k\,A\,\frac{\Delta\,T}{L} = 0.11\,\frac{\text{W}}{\text{mK}}\cdot 6\cdot 4\ \text{m}^2\cdot\frac{15\ \text{K}}{0.02\ \text{m}} = 1980\ \text{W}$$

4. (9 pts) Radiation from the sun strikes a blacktop road with a power of 1000W/m^2. What is the equilibrium temperature of the blacktop?
(You may ignore the effects of conduction and convection for this problem)

(A) 36.4 K **(B) 364 K** (C) 306 K (D) 3.06 K (E) 3060 K

at equilibrium:
$$\begin{aligned} P_{in} &= P_{out} \\ P_{in} &= \epsilon\cdot 1000\ \text{W/m}^2 \\ P_{out} &= \epsilon\cdot\sigma\cdot T^4 \qquad \text{per m}^2 \end{aligned}$$

$$\text{so } T = \left(\frac{1000}{\sigma}\right)^{0.25} = 364.4\ \text{K}$$

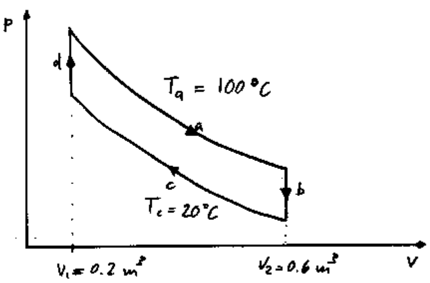
5. (9 pts) Calculate the mean free path of an atom in a liquid. Assume that one mole of the liquid occupies $2 \cdot 10^{-5}\text{m}^3$ and that the diameter of the atoms is $2 \cdot 10^{-10}\text{m}$ (=2 Å).

(A) 0.19 Å (B) 2.5 nm (C) 1.9 μm (D) 25 mm **(E) 1.9 Å**

$$\frac{N}{V} = \frac{N_A}{2 \cdot 10^{-5}\ \text{m}^3} = \frac{6.02 \cdot 10^{23}}{2 \cdot 10^{-5}\ \text{m}^3} = 3.01 \cdot 10^{28}/\text{m}^3$$

$$\text{so} \quad \lambda = \frac{1}{\sqrt{2}\,\pi\, d^2\, N/V} = 1.87 \cdot 10^{-10}\ \text{m} = 0.19\ \text{nm} = 1.9\text{Å}$$

6. (9 pts) The p-V diagram of an engine using 2.0 moles of an ideal gas is shown in the diagram below. What is the work done by the engine during one complete cycle?



(A) 146 J **(B) 1460 J** (C) 6813 J (D) -1460 J (E) -6813 J

$$\begin{aligned} W &= W_a + W_b + W_c + W_d \\ &= n\ R\ T_a\ \ln \tfrac{V_2}{V_1} + 0 + n\ R\ T_c\ \ln \tfrac{V_1}{V_2} + 0 \\ &= n\ R\ (T_a - T_c)\ \ln \tfrac{V_2}{V_1} = 2.0\ \text{mol} \cdot 8.31\ \text{J/molK} \cdot 80\ \text{K} \cdot \ln 3 \\ &= 1460.7\ \text{J} \end{aligned}$$

Problem 21-3, page 518

7. (9 pts) The temperature of 2.0 moles of an ideal monoatomic gas is raised from 300K to 400K while the volume of the gas was kept fixed. What is the change of entropy of the gas?

(A) 0 J/K (B) 4.8 J/K (C) -4.8 J/K **(D) 7.2 J/K** (E) -9.6 J/K

$$\Delta S = n\, C_V\, \ln \frac{T_f}{T_i} = 2.0 \text{ mol } \cdot \frac{3}{2} \cdot 8.31 \text{ J/molK} \cdot \ln \frac{400}{300} = 7.2 \text{ J/K}$$

8. (9 pts) What is the rms speed of helium atoms at room temperature (T=+20°C) ? (The molar mass of helium is 4.00g)

(A) 1352 m/s (B) 427 m/s (C) 4270 m/s (D) 1823 m/s (E) 3646 m/s

$$E_{kin} = \frac{3}{2}\, R\, T = \frac{3}{2}\, M\, \overline{v^2}$$

$$\text{or} \quad \sqrt{\overline{v^2}} = v_{rms} = \sqrt{\frac{3\, R\, T}{M}} = \sqrt{\frac{3 \cdot 8.31 \text{ J/molK} \cdot 293.15 \text{ K}}{0.004 \text{ kg/mol}}} = 1351.7 \text{ m/s}$$

Problem 20-7, page 493

Part II For questions 9 and 10, partial credit will be awarded if appropriate. Show all the work needed to get your answer.

9. [14 pts total]
Three moles of a monoatomic ideal gas occupy a fixed volume of $2.0\mathrm{m}^3$. The temperature of this gas is increased from $+20°$C to $+50°$C.

(a) (5 pts) By what factor does the pressure of the gas change?

$$p_1 V_1 = n R T_1 = p_2 V_2 = n R T_2$$
$$\frac{p_2}{p_1} = \frac{T_2}{T_1} = \frac{323.15 \text{ K}}{293.15 \text{ K}} = 1.102$$

Answer: 1.102

(b) (5 pts) How much heat is added to the gas?

$$\Delta Q = \Delta U - \Delta W$$
$$\Delta Q = \Delta U - 0 = n\, C_V \ \Delta T = 3 \cdot \frac{3}{2} \cdot 8.31 \text{ J/molK} \cdot 30 \text{ K} = 1122 \text{ J}$$

Answer: 1122 J

(c) (4 pts) How much work is done by the gas?

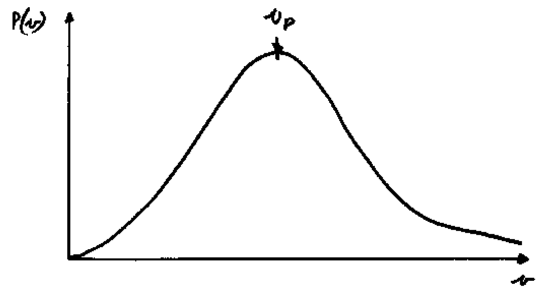
$$W = \int p \,\mathrm{d}V = 0$$

Answer: 0 J

10. [14 pts total]

Maxwell's speed distribution law can be written as $P(v) = b\,v^2\,e^{-v^2/v_0^2}$, where b and v_0 are constants at a given temperature.

(a) (7 pts) Sketch the general shape of this distribution in the graph below, and indicate with an arrow the most probable speed v_p.



(b) (7 pts) Find an expression for the most probable speed v_p in terms of the constants b and v_0?

$$\frac{dP}{dv} = \frac{d}{dv}\left(b\,v^2\,e^{-\frac{v^2}{v_0^2}}\right) = 0$$

$$= 2\,v\,e^{-\frac{v^2}{v_0^2}} + v^2\left[\frac{-2v}{v_0^2}\right]e^{-\frac{v^2}{v_0^2}} = 0$$

$$= 1 - \frac{v^2}{v_0^2} = 0 \qquad \text{or} \qquad v_p = v_0$$

Answer: $v_p =$	v_0

Useful constants and equations

Temperature and Heat:

Thermal expansion: $\Delta L/L = \alpha \Delta T$

Heat Capacity: $Q = c\, m\, (T_f - T_i)$, where c = specific heat; m =mass
for water $c = 4190$ J/kg·K

Heat of vaporization: $Q = L_V m$ for water $L_V = 2256$ kJ/kg

Heat of fusion: $Q = L_F m$ for water $L_F = 333$ kJ/kg

First Law

First law of thermodynamics: $\Delta U = \Delta Q - \Delta W$

Heat conduction: $H = Q/t = k\ A\ \frac{T_H - T_C}{L}$

Heat radiation: $P = \sigma\ \epsilon\ A\ T^4$ where $\sigma = 5.6703 \cdot 10^{-8}\ \mathrm{W/m^2 \cdot K^4}$

Kinetic Theory - Ideal Gas

Ideal gas las: $p\,V = n\,R\,T$ where $n = N/N_A$, and $N_A = 6.02 \cdot 10^{23}$ /mol
$R = 8.31$ J/mol·K and the Boltzmann constant
$k = R/N_A = 1.38 \cdot 10^{-23}$ J/K

Average translational kinetic energy: $\overline{E_{kin}} = \frac{3}{2}\ k\ T$ (per molecule)
$\overline{E_{kin}} = \frac{3}{2}\ R\ T$ (per mole)

Mean free path: $\lambda = \frac{1}{\sqrt{2}\pi d^2 N/V}$

Maxwell Speed distribution: $P(v) = 4\pi \left(\frac{M}{2\pi RT}\right)^{3/2}\ v^2\ e^{-\frac{Mv^2}{2RT}}$

Molar specific heat of ideal monoatomic gas: $C_V = \frac{3}{2}R$ and $C_p = C_V + R$

For ideal gas: $\Delta U = nC_V \Delta T$

Adiabatic process: $pV^\gamma = \mathrm{const}$ where $\gamma = C_p/C_V$

Isothermal process: $W = n\ R\ T\ \ln \frac{V_f}{V_i}$

Second Law - Entropy

Entropy change: $\Delta S = \int_i^f \frac{dQ}{T} = nR \ln \frac{V_f}{V_i} + nC_V \ln \frac{T_f}{T_i}$

2^{nd} law: $\Delta S \geq 0$

For ideal engine: $\epsilon = \frac{|W|}{|Q_H} = \frac{Q_H - Q_C}{Q_H} = \frac{T_H - T_C}{T_H}$

For ideal refrigerator: $K = \frac{|Q_C}{|W|} = \frac{Q_C}{Q_H - Q_C} = \frac{T_C}{T_H - T_C}$

Conversions

Heat: 1.0 cal = $3.969 \cdot 10^{-3}$ BTU = 4.186 J

Temperature: $T_C = T_K - 273.15 = \frac{5}{9}[T_F - 32]$

Length: 1Å= 0.1 nm = 10^{-10} m $\quad$ 1μm = 10^{-6} m