THE UNIVERSITY OF NEW SOUTH WALES
SCHOOL OF PHYSICS

PHYS2060 THERMAL PHYSICS

MIDSESSION EXAMINATION
SEPTEMBER 2007

Time allowed – 55 minutes (start 9:05 end 10:00)

Total number of questions – 3

Total number of marks – 30

Answer ALL questions

The questions are of equal value – each question is worth 10 marks

This examination paper has 4 pages.

This paper may be retained by the candidate

Portable battery-powered electronic calculators (without alphabetic keyboards) may be used.

All answers must be in ink. Except where they are expressly required, pencils may only be used for drawing, sketching or graphical work.

The following information is supplied as an aid to memory.

Boltzmann's constant $k_B = 1.38 \times 10^{-23}$ J/K
Avogadro's number $N_A = 6.022 \times 10^{23}$ mol^{-1}
Real gas constant $R = 8.314$ J/K.mol

Specific heat of liquid H_2O = 4.18 J/gK
Latent heat of the liquid-solid transition for H_2O = 333 J/g
Adiabatic constant for N_2 $\gamma = 1.4$
Molar mass of air = 29 g/mol

Ideal gas equation $PV = nRT = Nk_BT$

Maxwell's velocity distribution

$$D(v) = \left(\frac{m}{2\pi k_B T}\right)^{3/2} 4\pi v^2 \exp\left(-\frac{mv^2}{2k_B T}\right)$$

Question 1 (10 Marks)

(a) Far above the Earth's surface the gas kinetic temperature T (i.e. $T = \langle mv^2 \rangle / 3k_B$) is reported to be on order of 1000K. However, a person placed in such an environment would freeze to death rather than vaporize. Discuss in a few sentences. (Hint: You should consider the various heat transport mechanisms at play here, and their relative importance given your knowledge of the atmospheric pressure far above the Earth – but be concise).

(b) Clearly define and distinguish between temperature, heat and internal energy for a monatomic gas.

(c) Is it possible for two objects to be in thermal equilibrium if they are not in contact with each other? Can two bodies come to thermal equilibrium without being brought into contact? Briefly explain your answer.

Question 2 (10 Marks)

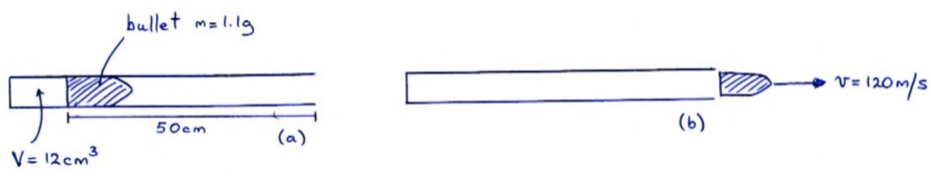
An air rifle shoots a lead bullet by allowing high-pressure air to expand, propelling the bullet down the rifle barrel. Because this process happens very quickly, no appreciable thermal conduction occurs, and the expansion is essentially adiabatic.

(a) What is the main characteristic of an adiabatic process? What are the two ways in which this can be achieved?

(b) Consider the rifle to be a cylinder containing n moles of an ideal gas. Starting from the expression $W = -\int PdV$ and using the condition PV^γ = constant, show that the work done on the gas is given by

$$W = \left(\frac{1}{\gamma - 1}\right)(P_f V_f - P_i V_i)$$

(c) Suppose that the rifle operates by allowing 12 cm^3 of compressed air at a initial pressure P to expand behind a 1.1g bullet, pushing it along the rifle barrel, which has a cross-sectional area of 0.03cm^2, as shown in sketch (a) below. The bullet travels 50cm along the barrel and emerges at a velocity of 120 m/s, as shown in sketch (b).



Calculate the initial pressure P required to achieve this. You may assume that air is an ideal gas with $\gamma = 1.4$. Note that you <u>cannot</u> assume that $P_f = 1$ atm, but if you look carefully, you'll notice that you can cancel it out. Hint: Be very careful regarding the sign of W.

Question 3 (10 Marks)

Maxwell's velocity distribution gives the probability density $D(v)$ as a function of particle velocity v for gases.

(a) Sketch a graph of the Maxwell distribution. Indicate on your graph the behaviour in the limits $v \to 0$ and $v \to \infty$, as well as the rough locations of the most probable, average and root-mean-square velocities (they don't need to be numerically accurate, but need to be in the correct order and on the correct side of the peak in the distribution).

(b) Sketch and briefly discuss how the Maxwell distribution behaves as a function of particle mass m for some constant given temperature T.

(c) How is Maxwell's velocity distribution used to find the probability that a randomly chosen particle has a velocity between v_1 and v_2?

(d) From the Maxwell distribution, show that the most probable speed of a gas molecule is given by:

$$v_{m.p.} = \sqrt{\frac{2k_BT}{m}}$$

(e) Starting from the result $\langle \frac{1}{2}mv^2 \rangle = 3/2k_BT$, show that:

(i) The rms velocity v_{rms} can be written as:

$$v_{rms} = \sqrt{\frac{3k_BT}{m}}$$

(ii) and that v_{rms} can also be written as:

$$v_{rms} = \sqrt{\frac{3P}{\rho}}$$

for an ideal gas, where P is the pressure in the gas and ρ is the gas density.