THE UNIVERSITY OF NEW SOUTH WALES
SCHOOL OF PHYSICS

PHYS2060 THERMAL PHYSICS

MIDSESSION EXAMINATION
SEPTEMBER 2006

Time allowed – 55 minutes (start 13:05 end 14:00)

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

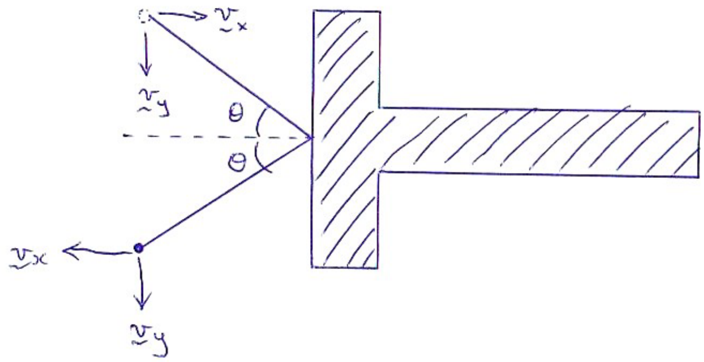
Ideal gas equation $PV = nRT = Nk_BT$

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)

The kinetic theory of gases links the macroscopic properties of a gas such as pressure, temperature and internal energy to the motions of the particles composing that gas. Considering a piston with area A in a cylinder full of gas, the force on the piston will be due to particles colliding with the piston as shown below.



(a) In one or two sentences each (i.e., don't do the whole derivation), explain why (i) the number of particles hitting the piston in time t is given by $n_c = nv_x tA$ and (ii) the momentum per particle is given by $dp/dn_c = -2mv_x$, where m is the mass, n is the number of particles per volume and v_x is the x-component of the velocity of a particle colliding with the wall.

(b) Using the results in (a), show that the collision of the gas particles with the piston results in a pressure $P = 2mnv_x^2$.

(c) Briefly explain the rationale behind i) replacing v_x^2 with $\frac{1}{2}\langle v_x^2\rangle$ and ii) replacing $\langle v_x^2\rangle$ with $1/3\langle v^2\rangle$, and (iii) show how these two replacements are used to obtain the generalised result for a gas in a box $PV = (2/3)N\langle mv^2/2\rangle$.

(d) 1 mole of monatomic He gas occupies a volume of 2 m^3 at a pressure of 12 atm, calculate the average kinetic energy per particle $\langle mv^2/2\rangle$.

(e) Using the principle of equipartition of energy, what is the temperature of the gas in (c).

(f) Define the internal energy U of a monatomic gas and using the generalised result in (b), give the relationship between P, V and U.

Question 2 (10 Marks)

A number of relationships between the pressure P, volume V and temperature T of a gas can be defined without recourse to kinetic theory.

(a) Starting from Boyle's law and Charles' law, briefly discuss how you can (i) obtain a third expression relating P and T at constant volume and (ii) obtain a combined gas law relating P, V and T.

(b) State Joule's law and briefly discuss the relationship between the combined gas law, the ideal gas law and the kinetic theory expression $PV = (2/3)U$.

(c) For an adiabatic process $PV^{\gamma} = C_0$, where C_0 is a constant. Show that $TV^{\gamma-1} = C_1$ where $C_0 \neq C_1$.

(d) On a graph of pressure P vs. volume V, draw lines corresponding to isobaric (const. P), isochoric (const. V), isothermal (const T) and adiabatic (const. Q)

processes. In particular discuss the relationship between the shapes of isothermal and adiabatic processes on a *PV*-diagram.

(e) Two identical pistons, both containing 10 L of N_2 gas at a pressure 1 atm at room temperature are prepared side by side. Both gases are compressed to a volume of 2 L, but the process in one piston is isothermal and the other piston is adiabatic.

  (i) Calculate the final pressures in the two pistons?

  (ii) What will be the temperature of the gas in the adiabatic piston at the end of the process?

Question 3 (10 Marks)

The first law of thermodynamics is usually written as $dU = Q + W$.

(a) Define each of the terms dU, W and Q and briefly explain the meaning and significance of the first law.

(b) Briefly discuss how compressive work in a gas is given by the expression $W = -\int PdV$.

(c) 1 L of air at 1 atm and 298 K is expanded isothermally to a pressure of 0.5 atm. Calculate the work done in this process and comment on the meaning of the sign of the result.

(d) Name the three mechanisms for heat transport. Choose one of these mechanisms and in a short paragraph (i.e., ¼ – ½ page), briefly discuss the key concepts involved in your chosen heat transport mechanism.

(e) A 200 mL cup of tea is made with boiling water. How many 1 cm^3 ice-cubes should you add to bring the tea down to a comfortable drinking temperature of 65°C. Assume that the ice is initially at 0°C, the latent heat of melting ice is 333 J/g, the specific heat of water is 4.18 J/g°C, and both ice and water have a density of 1 g/cm^3.