UNIVERSITY COLLEGE LONDON

University of London

EXAMINATION FOR INTERNAL STUDENTS

For The Following Qualifications:-

B.Sc. *M.Sci.*

Physics 1B28: Thermal Physics

COURSE CODE	:	**PHYS1B28**
UNIT VALUE	:	**0.50**
DATE	:	**15-MAY-06**
TIME	:	**14.30**
TIME ALLOWED	:	**2 Hours 30 Minutes**

06-C1157-3-120

Answer ALL SIX questions from Section A and THREE questions from Section B.

The numbers in square brackets in the right-hand margin indicate the provisional allocations of maximum marks per sub-section of a question.

The gas constant $R = 8.31$ J K^{-1} mol^{-1}.
Boltzmann's constant $k = 1.38 \times 10^{-23}$ J K^{-1}
Avogadro's number $N_A = 6.02 \times 10^{23}$ mol^{-1}
Acceleration due to gravity $g = 9.81$ m s^{-2}
Freezing point of water 0°C = 273.15 K

SECTION A

[Part marks]

1. (a) Write down the equation of state for an *ideal gas*. Explain the meaning of any symbols used. Sketch the isothermal dependence of pressure on volume of a gas when it behaves as [4]
   i) an *ideal* gas;
   ii) a *real* gas.

   (b) Explain under what physical conditions the ideal gas behaviour fails. Write down the van der Waals equation of state for a *real gas*. Explain the physical meaning of any parameters used. [3]

2. (a) State what is meant by the term Maxwell-Boltzmann '*distribution function*'. Sketch the Maxwell-Boltzmann distribution of molecular speeds. Indicate the positions of both the most probable and the root-mean-square speeds on the diagram. [5]

   (b) One mole of H_2, N_2, O_2, CH_4, and CO_2 gases are each at $T = 300$ K. Which gas, if any, has the highest average kinetic energy per mole? Molecules of which gas have the highest average speed? Explain your answers. [2]

3. (a) Sketch the potential energy of interaction between the two H atoms in an H_2 molecule as a function of their separation. Mark the location of the equilibrium separation between atoms in a molecule of H_2. Describe the physical origins of the interactions in the molecule at long, short and intermediate separations between the H atoms. [4]

   (b) Explain what is meant by the *internal energy* of a gas in classical thermodynamics. Write down an expression for the internal energy of an ideal monatomic gas. Explain how it is related to the molar heat capacity of a gas at constant volume. [3]

4. (a) One mole of He gas, initially at $P_1 = 101.3$ kPa, $T_1 = 0.0$ °C, undergoes an isovolumetric process in which its pressure falls to half its initial value. [4]
   i) Calculate the work done by the gas;
   ii) Calculate the final temperature of the gas;
   iii) The helium gas then expands isobarically to twice its volume; calculate the work done by the gas.

   (b) How much heat is required to heat 0.3 kg of aluminium, which is initially at 20 °C, to its melting point and then to convert it all to liquid? The melting temperature of aluminium is 660 °C, the specific heat is equal to 900 J $kg^{-1}K^{-1}$ and the latent heat of fusion is equal to 3.97×10^5 J kg^{-1}. [2]

5. (a) State what is meant by a quasi-static *adiabatic* and quasi-static *isothermal* process. Explain how does the internal energy of an ideal gas changes when it undergoes: [4]
   i) a quasi-static *adiabatic* expansion;
   ii) a quasi-static *isothermal* expansion;
   iii) a quasi-static *isobaric* expansion.

   (b) A car receives energy from the fuel at a rate of 72 kJ s^{-1}. It uses 9 kJ s^{-1} to move along the road. Calculate (i) how much heat is lost as waste per second, and (ii) the car's efficiency. [2]

6. (a) Write down a statement of the *Second Law of Thermodynamics*. Explain what is meant by a *reversible* process in thermodynamics, and give two examples of real processes which are irreversible. [4]

   (b) An ideal gas is confined to a cylinder by a piston. The piston is slowly pushed inside the cylinder so that the gas temperature remains at 20 °C. During the compression, 730 J of work is done on the gas. Find the entropy change of the gas. [3]

SECTION B

[part marks]

7. (a) An ideal gas has a density of 1.78 $kg\,m^{-3}$ and is contained in a volume of 44.8×10^{-3} m^3. The temperature of the gas is 0.0 °C and the pressure is 1.01×10^5 Pa. [6]

   i) What is the root mean square speed of the gas molecules?
   ii) How many moles of the gas are present?
   iii) Assuming that the gas is monatomic, calculate the internal energy of the gas.

(b) A cylinder containing gas at 300 K is divided into two parts, A and B, of equal volume by a frictionless piston of cross-sectional area of 15 cm^2. Each part has a volume of 100 cm^3 and equal initial pressure. The temperature of the gas in part A is raised to 373 K, while the part B is maintained at the original temperature. The piston and walls are perfect insulators. Calculate how far will the piston move due to the change in temperature. [7]

(c) Hailstones hit a roof perpendicularly. Each hailstone has a mass m and speed v. There are N hailstones in a volume V approaching the roof. Assume that when hailstones strike the roof, they bounce back elastically. Derive an expression for the pressure on the roof due to hailstones hitting it. [7]

8. (a) Explain why for an ideal gas the two molar heat capacities, C_P at constant pressure and C_V at constant volume, have different magnitudes. Derive a relationship for the difference $C_P - C_V$. [8]

(b) Sketch a $P - T$ phase diagram of a simple substance indicating each phase. Explain the physical meaning of the lines on the diagram. Show the positions of the triple point and the critical point and explain their physical meanings. [7]

(c) The volume of 1 kg of liquid water at 100 °C is 1.0×10^{-3} m^3. The volume of the vapour formed when it boils at this temperature and at standard atmospheric pressure of 1.01×10^5 Pa is 1.671 m^3. The latent heat of vaporization of water is equal 2.26×10^6 J kg^{-1}. [5]

   i) Calculate how much work is done by the water vapour in pushing back the atmosphere.
   ii) Calculate the increase in the internal energy of water when the liquid evaporates.

9. (a) 60 g of CO_2 gas at 350 K is confined to a volume of 400 cm^3. For carbon dioxide gas (CO_2), the constants in the van der Waals equation of state are $a = 0.364$ J m^3 mol^{-2} and $b = 4.27\times10^{-5}$ m^3 mol^{-1}. The molar mass of carbon is 12 g mol^{-1} and the molar mass of oxygen is 16 g mol^{-1}. [8]

i) Find the pressure of the gas using both the ideal gas equation and the van der Waals equation of state.
ii) Explain why the values of pressure obtained using these equations of state differ.

(b) Calculate the density of mercury at 110 °C, if its density at 0.0 °C is 13600 kg/m^3. The coefficient of volume expansion of mercury $\beta = 1.82\times10^{-4}$ K^{-1}. [5]

(c) In a double-glazed window the panes of glass are separated by 5 cm. Assume that insulation is provided only by the air between the glass panes. [7]

i) Calculate the rate of transfer of heat by conduction from the warm room (25 °C) to the cold exterior (-10°C) through a window of area 1 m^2. The thermal conductivity of air is 0.023 W/m °C.
ii) Explain why the coefficient of thermal conductivity of H_2 (0.172 W/m °C at 25 °C) is much bigger than that of the air.

10.(a) Calculate how much ice (at a temperature of -20 °C) you would need to add to a cup of coffee to bring the temperature of coffee down from 85 °C to 60 °C. The mass of coffee is 340 g. Assume that all the ice you add will melt, that coffee has the same heat capacity as water, and that no heat is lost to the coffee cup or surroundings. The specific heat capacity of water is equal 4186 J kg^{-1} K^{-1}, the specific heat capacity of ice is 2090 J kg^{-1} K^{-1}, and the latent heat of melting ice is 3.33×10^5 J kg^{-1}. [5]

(b) As a sample of gas is allowed to expand quasi-statically and adiabatically, its pressure drops from 130 kPa to 100 kPa, and its temperature drops from 300 K to 280 K. [7]

i) Explain whether the gas is monatomic or diatomic.
ii) Explain which degrees of freedom the gas molecules have and which of these are likely to be activated at these temperatures.

(c) A monatomic ideal gas occupies a volume of 1.0 m^3 at 0.0 °C and pressure of 1.01×10^5 Pa. Calculate the final volume and work done during adiabatic reversible expansion of the gas, if the final pressure of the gas is equal to 1.01×10^4 Pa. [8]

11. (a) A steam engine operating between a boiler temperature of 500 °C and a condenser temperature of 45 °C is using 500 J per cycle. Its efficiency is 30% of that for a Carnot engine operating between these temperature limits and using the same amount of heat. [9]

i) Draw a P-V diagram of the Carnot operation cycle. Show in this diagram where heat enters and leaves the steam. Calculate the thermal efficiency and the amount of heat wasted per Carnot cycle.
ii) Calculate the amount of work performed and the amount of heat wasted by the *real* engine per cycle.
(iii) Explain why the efficiency of a *real* engine differs from that of the ideal Carnot engine

(b) Derive an expression for the change in entropy of an ideal gas when its volume and temperature change reversibly from V_1 at T_1 to V_2 at T_2. [4]

(c) A sample of an ideal gas that initially occupies 11.0×10^{-3} m^3 at 270 K and pressure 1.20×10^5 Pa is compressed reversibly and isothermally. To what volume must the gas be compressed to reduce its entropy by 3.0 J K^{-1}? [7]

Explain why the entropy of the gas is reduced and why your result is not a violation of the entropy statement of the Second Law.