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	:	**18-MAY-04**
TIME	:	**10.00**
TIME ALLOWED	:	**2 Hours 30 Minutes**

04-C1074-3-140

TURN OVER

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) Explain what is meant by an *ideal gas* in classical thermodynamics. Under what physical conditions do the assumptions underlying the ideal gas model fail? [4]

(b) Write down the equation of state for an *ideal gas* and one for a *real gas*. Explain the meaning of any symbols used. [4]

2. (a) Write down an expression for the average translational kinetic energy of a mole of an ideal classical gas at temperature T. Explain how this expression is related to the *principle of equipartition of energy*. [2]

(b) Calculate the root-mean-square speed of oxygen molecules at T = 300°C. The molar mass of oxygen is equal to 32 g·mol^{-1}. [2]

(c) Sketch the Maxwell-Boltzmann distribution of molecular speeds, and indicate the positions of both the most probable and the root-mean-square speeds on the diagram. [2]

3. (a) A fluorine atom (F) has 9 electrons. Write down all the quantum numbers for the valence electrons in an F atom, and briefly discuss their meaning. [5]

(b) Sketch a potential energy and force of the interaction between the two F atoms in an F_2 molecule as a function of their separation. Show the location of the equilibrium distance between atoms in a molecule in both graphs. [3]

4. (a) Derive the expression for the work done by an ideal gas undergoing a reversible isothermal expansion from volume V_i to V_f. [3]

(b) 2 g of water of volume 2 cm^3 are boiled at a constant pressure of 1.013×10^5 Pa to become 3342 cm^3 of steam. The heat of vaporization of water at this pressure is $L_v = 2.256\times10^6$ J·kg^{-1}. Compute: [3]

i) the change in internal energy of the water, and;
ii) the work done by the water when it vaporizes.

5. An internal combustion engine takes in 20,000 J of heat and delivers 4,000 J of mechanical work per cycle. [6]

   i) What is the thermal efficiency of this engine?

   ii) How much heat is discarded during each cycle?

   iii) Assuming that this engine is a Carnot engine with cold reservoir at 20^{o}C, find the combustion temperature.

6. A 2 kg block of ice at 0.0^{o}C melts inside a large room that has a temperature of 25.0^{o}C. Treat the ice and the room as an isolated system and neglect the change of the room temperature due to the ice melting and warming up to room temperature. Calculate the net entropy change of the system during this process. [6]

   The latent heat of melting ice is $L_f = 334\times10^3$ $J\cdot kg^{-1}$ and the specific heat of water is 4190 $J\cdot kg^{-1}\cdot K^{-1}$.

SECTION B

[part marks]

7. (a) Assume that air is simply a mixture of N_2 and O_2, and that the mass of one mole of the air is 29.00 g. The molar mass of N_2 is 28.02 $g \cdot mol^{-1}$ and the molar mass of O_2 is 32.00 $g \cdot mol^{-1}$. [8]

i) What is the fraction of N_2 and O_2 in air?
ii) At sea level, the total pressure of air is 1 bar. Calculate the partial pressure due to N_2 and O_2 at sea level.
iii) Assuming thermal equilibrium throughout the atmosphere and using the law of atmospheres calculate the partial pressure of O_2 at the height of 2,000m, where the temperature is 0.0°C.

(b) For carbon dioxide gas (CO_2), the constants in the van der Waals equation of state are $a = 0.364$ $J{\cdot}m^3 \cdot mol^{-2}$ and $b = 4.27\times10^{-5}$ $m^3 \cdot mol^{-1}$. [6]

i) If 1 mole of CO_2 gas at 350 K is confined to a volume of 400 cm^3, find the pressure of the gas using both the ideal gas equation and the van der Waals equation.
ii) Give physical reasons for the influence on the pressure of non-zero a and b parameters in the van der Waals equation.

(c) Explain what is meant by the *critical point* on a *P-V-T* phase diagram. On a *P-V* diagram, draw the isotherms for a gas at temperatures above and below the critical point and explain the difference in their behaviour. [6]

8. (a) Derive an expression for the heat capacity C_V of a monatomic ideal gas at constant volume. [4]

(b) Explain the nature of the chemical bonding in an H_2 molecule. Draw a graph of the dependence of the heat capacity at constant volume of the H_2 gas on temperature and explain this behaviours. [5]

(c) Explain why the molar heat capacities of an ideal gas at constant pressure and constant volume are different and derive a relationship between them. [6]

(d) You would like to cool 0.25 kg of water, initially at 25°C, by adding ice, initially at -20°C. How much ice should you add so that the final temperature will be 0°C with all ice melted? The heat capacity of the container may be neglected. The specific heat capacity of ice is 2.1×10^3 $J \cdot kg^{-1} \cdot K^{-1}$, the specific heat of water is 4190 $J \cdot kg^{-1} \cdot K^{-1}$, and the latent heat of melting ice is $L_f = 334\times10^3$ $J \cdot kg^{-1}$. [5]

9. (a) Derive an approximate expression for the latent heat of sublimation of a mole of a rare (noble) gas solid in terms of the strength of interactions between a pair of atoms. Assume that the interaction between atoms can be well described by the Lennard-Jones potential. [8]

(b) A glass flask with volume 200 cm^3 is filled to the brim with liquid mercury at 20°C. How much mercury overflows when the temperature of the system is raised to 100°C? The coefficient of linear expansion of glass is $\alpha = 0.40\times10^{-5}$ K^{-1} and the coefficient of volume expansion of mercury is $\beta = 18\times10^{-5}$ K^{-1}. [6]

(c) After equilibration, the glass flask with liquid mercury at 100°C described in the previous section is left on a bench to cool to room temperature 20°C. List the main mechanisms of heat transfer that eventually lead to the cooling of the flask and briefly explain their origins. [6]

10. (a) An ideal gas at equilibrium occupies a volume of 0.68 m^3 and is at a pressure of 3.0×10^5 Pa. The gas then undergoes a quasi-static isothermal expansion until its volume is 1.26 m^3. Calculate the new equilibrium gas pressure and the work done by the gas in the process. [5]

(b) Derive an expression for the work done by an ideal gas in an adiabatic expansion. [6]

(c) A system proceeds from an equilibrium state i to an equilibrium state f by a path A and then returns to the equilibrium state i by a different path B. Along path A the system extracts heat of amount 40 J from the surroundings and does 20 J of work on the surroundings. Along path B the system has 10 J of work performed on it by the surroundings. Calculate the amount of heat absorbed by the system along path B. [5]

(d) Give the Nernst-Simon formulation of the Third Law of thermodynamics, and explain why the entropy of N_2 (molar mass 28.02 g·mol^{-1}) will never reach zero as the temperature goes to the absolute zero. [4]

11. (a) You are called upon to design a Carnot engine that has 2 moles of a monatomic ideal gas as its working substance, and which operates from a high temperature reservoir at 500°C. The engine is to lift a 15 kg weight 2 m per cycle, using 500 J of heat input. The gas in the engine chamber can have a minimum volume of 5 L during the cycle. [8]

i) Draw a P-V diagram of this cycle. Show in this diagram where heat enters and leaves the gas.

ii) What is the thermal efficiency of the engine?

iii) What is the temperature of the cold reservoir?

iv) How much heat energy does the engine waste per cycle?

v) What is the maximum pressure that the gas chamber will have to withstand?

(b) Explain how the efficiency of a real engine will differ from that of the ideal Carnot engine, and why. [3]

(c) 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. [5]

(d) A thermally insulated box of volume 2 m^3 is separated into two sections of equal volume by a removable partition. This first section contains 1 mol of pure helium and the second section contains 1 mol of pure argon, both gases are at the same temperature T. Calculate the change in entropy when the partition is removed and the gases are allowed to mix, assuming that both gases are ideal. [4]