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	:	**20-MAY-05**
TIME	:	**14.30**
TIME ALLOWED	:	**2 Hours 30 Minutes**

05-C1073-3-140

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 under what physical conditions a gas behaves as an *ideal gas* in classical thermodynamics, and write down the equation of state for an *ideal gas*. Explain the meaning of any symbols used. [3]

(b) Explain what is meant by an adiabatic process in thermodynamics. Write down a relationship between pressure and volume of an ideal gas experiencing an adiabatic process, and explain the meaning of any symbols used. Calculate the entropy change of a gas in an adiabatic reversible process. [3]

2. (a) Sketch the *Maxwell-Boltzmann distribution* of molecular speeds and explain its physical meaning. Indicate the positions of both the most probable and the root-mean-square speeds on the diagram. [4]

(b) Write down an expression for the average translational kinetic energy of a mole of an ideal classical gas at temperature T. Calculate the root-mean-square speed of nitrogen molecules at $T = 300$°C. The molar mass of nitrogen is equal to 28.02 g·mol^{-1}. [3]

3. (a) State Avogadro's hypothesis and calculate how many molecules are in 3 moles of oxygen. [2]

(b) Sketch the potential energy of interaction between the two Ar atoms in an Ar_2 molecule as a function of their separation. Show the location of the equilibrium separation between atoms in a molecule of Ar_2. Describe the physical origins of the interactions in the molecule, at long and short separations between the Ar atoms. [4]

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

(b) Victoria Falls in Africa is 122 m in height. Calculate the rise in temperature of the water if all the potential energy lost in the fall is converted to heat. List the major physical reasons which may affect the accuracy of your prediction. The heat capacity of water is 4184 J·kg^{-1}·K^{-1}. [4]

5. (a) Write down a statement of the *First Law of Thermodynamics*. Explain any symbols you use. Describe your sign convention for work associated with a thermodynamic system. Explain what is meant by the *internal* energy of a system. [4]

(b) Calculate the maximum amount of work that a Carnot engine can perform per 1 kJ of heat input if it absorbs heat at 427 °C and exhausts heat at 177 °C. What is the efficiency of this engine? [3]

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) A 100 g block of ice at 0 °C melts inside a large room that has a temperature of 0 °C. Treat the ice and the room as an isolated system and neglect the change of the room temperature due to the ice melting. Calculate the net entropy change of the system during this process. The latent heat of melting ice is $L_f = 334\times10^3$ J·kg^{-1}. [3]

SECTION B

[part marks]

7. (a) A volume V_0 of helium is confined within a chamber. The initial pressure is P_0 (atmospheric pressure), and the initial temperature is T_0. Helium is a monatomic gas, which we will treat as an ideal gas. [8]

i) Find the number N_0 of atoms of helium in the sample. Your answer should be expressed exclusively in terms of the given quantities, but it may also contain k (the Boltzmann constant) or R (the gas constant).

ii) Express the internal energy U_0 of the gas in terms of the given quantities.

iii) Suppose the gas is allowed to expand to $V_1 = 1.5\times V_0$, while it is being heated at just the right rate to keep the pressure constant. During the expansion, how much heat Q_I has to be added to the gas? Express your answer in terms of P_0 and V_0.

(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 meaning. [7]

(c) A liquid partially fills a thermally insulated container and is in thermal equilibrium with a gas inside the container. Discuss why the temperature of the liquid decreases when part of the gas is pumped out of the container. [5]

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. [7]

(b) Explain the nature of chemical bonding in a H_2 molecule. Sketch a graph of the dependence of the heat capacity at constant volume of the H_2 gas on temperature above the boiling temperature, and explain qualitatively why C_V at 30K is lower than that at 300K; and at 300K is lower than that 3000K. [8]

(c) As a sample of gas is allowed to expand quasi-statically and adiabatically, its pressure drops from 120 kPa to 100 kPa, and its temperature drops from 300 K to 280 K. Explain whether the gas is monatomic or diatomic. [5]

PLEASE TURN OVER

9. (a) Describe the nature of the interaction between atoms in a rare (noble) gas. Derive an approximate expression for the latent heat of sublimation, L_s, of a mole of such a solid in terms of the strength of interactions between a pair of atoms. [8]

(b) An iron circular disk has a diameter of 60 mm and is 0.010 mm too large to pass through a hole in a brass plate when the disk and plate are at a temperature of 30 °C. The coefficient of linear expansion of brass is $\alpha_{Brass} = 1.9\times10^{-5}\ K^{-1}$ and the coefficient of linear expansion of iron is $\alpha_{Iron} = 1.2\times10^{-5}\ K^{-1}$. [8]

i) If the disk and the plate are at the same temperature, at what temperature will the disk just fit into the hole?

ii) Explain briefly the physical origins of the thermal expansion of simple solids, assuming that the interaction between atoms can be well described by the Lennard-Jones potential.

(c) An iron rocket fragment initially at -100 °C enters the atmosphere almost horizontally, and quickly melts completely. Assuming that heat loss from the fragment to the air is negligible, calculate the minimum velocity it must have had when it entered the atmosphere. The specific heat of iron $c = 448\ J{\cdot}kg^{-1}{\cdot}K^{-1}$ and the specific heat of melting iron $L_f = 2.67\times10^5\ J{\cdot}kg^{-1}$. The melting temperature of iron is 1535 °C. [4]

10. (a) 48.0 g of ice at 0 °C is placed in an aluminium calorimeter can of mass 2.0 g, also at 0 °C. 75.0 g of water at 80 °C are then poured into the can. The specific heat of water is $1.00\ cal{\cdot}g^{-1}{\cdot}K^{-1}$ and that of aluminium is $0.22\ cal{\cdot}g^{-1}{\cdot}K^{-1}$. The latent heat of fusion of ice is $79.8\ cal{\cdot}g^{-1}$. Assuming that all of the ice has melted, calculate the final temperature of the whole system. [4]

(b) Derive an expression for the work done by a system undergoing isothermal compression (or expansion) from volume V_1 to V_2 for a real gas which obeys the van der Waals equation of state. [5]

(c) A cylinder of ideal gas is closed by an 8 kg movable piston. The area of one face of the piston is 60 cm^2. Atmospheric pressure is 100 kPa. When the gas is heated from 30 to 100 °C, the piston rises 20 cm. The piston is then fastened in place and the gas is cooled back to 30 °C. Calling Q_1 the heat added to the gas in the heating process and $|Q_2|$ the heat lost during cooling, find the difference between Q_1 and $|Q_2|$. [6]

(d) How much water at 100 °C could be evaporated per hour by the heat transmitted through a 1 cm × 1 cm steel plate 0.2 cm thick, if the temperature difference between the plate faces is 100 °C. For steel, the coefficient of thermal conductivity $K = 0.11\ cal{\cdot}s^{-1}{\cdot}cm^{-1}{\cdot}K^{-1}$. The latent heat of vaporization of water is $540\ kcal{\cdot}kg^{-1}$. [5]

11. (a) A steam engine operating between a boiler temperature of 220 °C and a condenser temperature of 35 °C delivers 6 kW of power. If its efficiency is 30% of that for a Carnot engine operating between these temperature limits, how much heat is absorbed each second by the boiler? How much heat is exhausted to the condenser each second? [6]

(b) How many kilograms of water at 0 °C can a freezer with a coefficient of performance 5 make into ice cubes at 0 °C, with the work input of 3.6×10^6 J. The latent heat of freezing water is 3.33×10^5 J·kg^{-1}. [4]

(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. [4]

(d) An ideal gas is confined to a cylinder by a piston at 20 °C. The piston is slowly pushed in so that the gas temperature remains at 20 °C. During the compression, 730 J of work is done on the gas. [6]

i) Find the entropy change of the gas

ii) Explain why your result is not a violation of the entropy statement of the second law.