THERMAL AND KINETIC PHYSICS (PHY 214)

Coursework 5 : Week 5

ISSUE: Tuesday 26 October, 2010 HAND-IN: Tuesday 02 November, 2010

Students name (top left corner), course title & exercise number and exercise group (top right corner) should appear on every sheet of the submitted coursework and sheets should be firmly held together. A stapler is available if needed from the secretaries office.

Hand-in of worked exercises must take place by 4:00 p.m. on the above date at the labeled box provided outside the Teaching Administrators office on the first floor.

This time will be strictly adhered to and no late working will be accepted without written explanation to the course organiser. The solutions will appear shortly after this time on the TKP website.

Each coursework is worth 40 marks and the aggregate coursework mark will count 10% towards the final mark. An indicative mark scheme is given with each question. **Note**: ***I want to see the method of solution. No credit will be given for simply writing down the answer.***

Students should collect new exercise sheets in the Tuesday lecture or download them from the Web. Marked exercises will be returned in exercise classes or via the box outside the Teaching Administrators office on the first floor.

QUESTION 1: (20 marks) (From a past examination paper)

An engine is constructed with an ideal monatomic gas as the working substance for which the internal energy is $U = \frac{3}{2}PV$. It operates reversibly in a cycle with three legs a $\rightarrow$ b $\rightarrow$ c $\rightarrow$ a.

The process a $\rightarrow$ b is an isobaric expansion during which heat Q_1 is absorbed. The process b $\rightarrow$ c is an adiabatic expansion while the final process c $\rightarrow$ a is an isothermal compression during which waste heat Q_2 is expelled.

a) Sketch the engine cycle in a P - V diagram. **[3mks]**

b) Apply the First Law to the processes a $\rightarrow$ b and c $\rightarrow$ a to obtain expressions for Q_1 and Q_2. Express your answers in terms of P_a, V_a, V_b and V_c. **[6mks]**

c) Show that the efficiency of this engine can be expressed as

$$\eta_E = 1 - \frac{2}{5}\frac{ln\left(P_a / P_c\right)}{\left(P_a / P_c\right)^{1-1/\gamma} - 1}$$

where γ is the adiabatic constant for the gas. **[6mks]**

d) For a particular engine of this type, P_c is 1 atm while P_a is limited by the strength of the materials used in the engine to be no greater than 32 atm. What is the maximum efficiency attainable under this restriction? If we can supply heat energy to the engine at the rate of 5 kW, how much power will it produce at this maximum efficiency? An environmentalist protests about the waste of energy represented by the heat energy Q_2 which is just thrown away. From the viewpoint of thermodynamics what would you say to him? **[5mks]**

QUESTION 2: (20 marks)

a) (From Question 1 Chapter 5 Finn)

A bucket containing 5 kg of water at 25 °C is put outside a house so that it cools to the temperature of the outside at 5 °C. What is the entropy change of the water? (c_P for water may be taken as 4.2×10^3 J kg^{-1} K^{-1}.) **[2mks]**

b) (From Question 2 Chapter 5 Finn)

Calculate the entropy change of the water for each of the following processes:

(i) 10 g of water at 100 °C and a pressure of one atmosphere cooling to 0 °C at the same pressure. (Take the specific heat per unit mass of water c_P to be constant at 4.2 J g^{-1} K^{-1} over this temperature range.) **[2mks]**

(ii) 10 g of water at 0 °C and a pressure of one atmosphere freezing into ice at the same pressure and temperature. (The latent heat of fusion of ice is 333 J g^{-1} .)

[3mks]

c) (From Question 3 of the 2003 Exam)

(i) State (without derivation) the definition of entropy in terms of reversible heat flows. State the entropy form of the Second Law of Thermodynamics for processes undergone by a thermally isolated system. **[2mks]**

(ii) A bucket containing 4 kg of water at a temperature of 10 °C is placed outside in winter on a cold day when the ambient temperature is -5 °C. What will be the final equilibrium state of the water? **[2mk]**

(iii) Calculate the entropy change of the water between its initial and final states. **[6mks]**

(iv) Calculate the total heat loss by the water in this process and hence calculate the entropy change of the outside environment. **[2mks]**

(v) Show that the Second Law of Thermodynamics is satisfied for this process. **[1mk]**

HINT: Remember that entropy changes occur not only in heating and cooling but also in freezing and melting. Check also in the table of constants that I gave you what the specific heat per unit mass of ice is.