College of Science and Engineering
School of Physics & Astronomy

Thermodynamics

SCQF Level 9, PHYS09021

Monday 6th May 2013

14.30 – 16.30

Chairman of Examiners
Professor A Trew

External Examiner
Professor D McMorrow

Answer ALL of the questions in Section A and TWO questions from Section B.

The bracketed numbers give an indication of the value assigned to each portion of a question.

Only the supplied Electronic Calculators may be used during this examination.

A sheet of standard constants is available for use during this examination.

ANONYMITY OF THE CANDIDATE WILL BE MAINTAINED DURING THE MARKING OF THIS EXAMINATION.

Section A: Answer ALL of the questions in this Section

A.1. Define the thermodynamic potentials H, F and G in terms of pressure, volume temperature, entropy and internal energy. **[2]**

Use the central equation $dU = TdS - PdV$ to express dH, dF and dG in terms of changes in their natural variables. **[3]**

A.2. What are the four stages of the Carnot cycle?

Draw an indicator diagram (P vs V) showing flows of heat and work into and out of the working substance. **[5]**

A.3. A rock at 400K with heat capacity c_p is placed in a very large lake at 300K. The rock cools rapidly to 300K. Calculate the entropy change, due to this process, of

a) the rock.

b) the lake.

[5]

A.4. The imperfectly-insulated cool box of a Carnot refrigerator at temperature T loses heat at a rate proportional to the difference between T and the atmosphere temperature T_0: i.e. $\dot{Q} = B(T_0 - T)$, with B=4JK^{-1}s^{-1}.

Show that the temperature of the cool box is given by the solution of:

$$T^2 - (2T_0 + \frac{W}{B})T + T_0^2 = 0,$$

and evaluate this temperature in the case where the refrigerator runs at power input $W = 1200\,\mathrm{J\,s^{-1}}$, and pumps heat to the atmosphere at $T_0 = 300\,\mathrm{K}$. **[5]**

Section B: Answer TWO of the following THREE questions

B.1. a) State a version of the Third Law of Thermodynamics. **[2]**

b) By considering S(T, V), show that:

$$\Delta S = \int \frac{c_V}{T} dT + \int \left(\frac{dP}{dT}\right)_v dV.$$

[4]

c) Calculate an expression for the change in entropy when one mole of a monoatomic ideal gas is heated from T_0 to T at constant pressure. **[5]**

d) For an ideal gas at constant pressure, sketch the dependence of entropy on temperature. **[4]**

e) Discuss the behaviour of the entropy of an ideal gas as $T \to 0$. What can one conclude about the ideal gas equations in this limit? **[5]**

B.2. a) Explain the assumptions which allow us to write

$$dS = \left(\frac{\partial S}{\partial T}\right)_V dT + \left(\frac{\partial S}{\partial V}\right)_T dV$$

requiring only *two* partial derivatives. Give an example where more than two partial derivatives would be required. **[5]**

b) Use Maxwell relations and the triple product rule to show that the ratio of constant-pressure and constant-volume heat capacities is the same as the ratio of isothermal and adiabatic bulk moduli, i.e.

$$\frac{C_P}{C_V} = \frac{K_s}{K_T}.$$

[7]

c) Use this result, and the fact that, $C_p - C_v = TV\beta^2 K_T$ to evaluate the adiabatic bulk moduli for

i) a monatomic ideal gas **[2]**

ii) a diatomic ideal gas. **[2]**

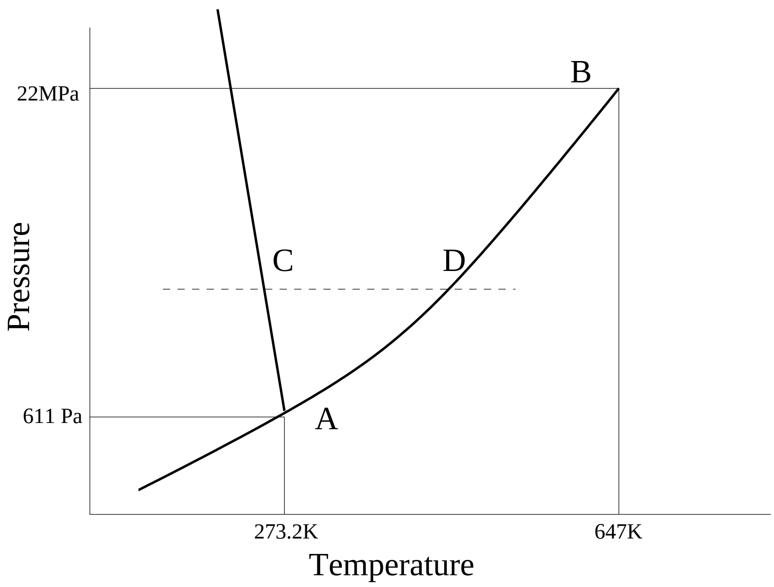
d) Discuss which of K_s and K_T would be appropriate for calculating

i) the density increase of a tin can as it falls to the ocean floor **[2]**

ii) the speed of sound in an ideal gas. **[2]**

(You do not need to evaluate these quantities.)

B.3. The figure shows a schematic P-T phase diagram for water.



a) Copy the figure into your script, labelling each phase. **[1]**

b) What is the significance of the points marked A and B **[2]**

c) Write down the Clausius-Clapeyron equation **[2]**

d) What should happen to the slope of the solid-gas boundary as $T \to 0$? **[2]**

On heating at atmospheric pressure (0.1MPa, dotted line) two phase transitions occur.

e) Explain, giving at least one example, what is meant by a first order phase transition. **[5]**

Sketch graphs of the entropy and Gibbs free energy of water against temperature along the dashed line, indicating the transition points C and D. Note carefully any discontinuities in the curves, or in the gradient of the curves. **[2,2]**

f) Given that the latent heat of melting for water is 334kJ/kg, and that 90% of an icecube in a glass of water is below the surface, calculate the slope of the phase line at C. **[4]**