SURNAME:________________ INITIALS:________________

STUDENT NUMBER:________________

UNIVERSITY of JOHANNESBURG
Physics 2Y (PHY002Y) : July supplementary exam
Thermal Physics

	Student's mark	Questions' mark
Q1		22
Q2		26
Q3		12
Total		**60**

Date: 27 July 2016

Examiner: Dr. B.P. Doyle

Moderator: Prof. S. Razzaque

Time: 120 Minutes

Pencils and cell-phones are not allowed.
Answer all the questions.
This paper consists of 12 pages including this cover page and the information sheet.

Leave any calculations in numbers if you don't have a calculator.

Where necessary, explain what you are doing in derivations.

IF YOU DO NOT UNDERSTAND ANY OF THE LANGUAGE USED, ASK!!!

Question 1 [22]

(1a) Give an example of a process in which no heat is added to a system, but its temperature increases. Then give an example of the opposite: a process in which heat is added to a system but its temperature does not change. [2]

Do not write in the margins

(1b) Calculate the average volume per molecule for an ideal gas at room temperature and at atmospheric pressure. Use this to work out the average distance between molecules.

[4]

(1c) For an ideal gas of one molecule in a smooth cylinder of volume V, with a piston at one end, show that:

1. the average pressure is given by: $\overline{P} = \dfrac{mv_x^2}{V}$. [6]
2. From this derive an expression for the average translational kinetic energy of a large number of identical molecules. [4]

(1d) Derive the expression for the work done when compressing an ideal gas isothermally. [4]

(1e) Explain why an adiabat on a pressure-volume graph starts on one isotherm and ends on another. [2]

Question 2 [26]

(2a) Explain the following terms, giving a suitable example for each:

(i) microstate [1]

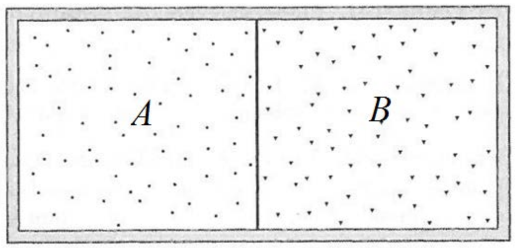
(ii) macrostate [1]

(iii) multiplicity [1]

(2b) Derive an expression for the multiplicity of a two-state system, such as a set of coins. Explain your reasoning clearly. [7]

(2c) Derive a formula for the multiplicity of an Einstein solid containing a large number of oscillators and energy units, in the high-temperature limit. [8]

(2d) Suppose that we have two different monoatomic ideal gases, A and B, each with the same energy, volume and number of particles. They occupy the two halves of a chamber, separated by a partition, as shown in the below figure. Calculate the entropy increase if the partition is removed. [4]



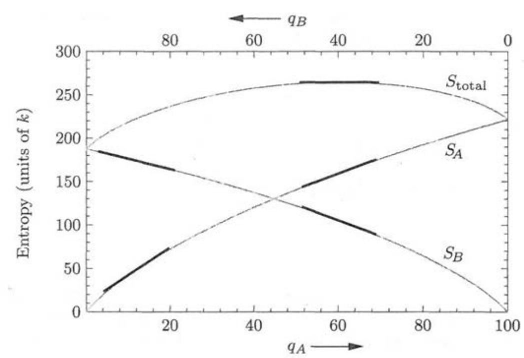
(2e) Two Einstein solids share 40 units of energy. Solid A has 15 oscillators and solid B has 20 oscillators.

(i) How many possible macrostates are there? [1]

(ii) What is the probability of finding all the energy in A? [3]

Question 3 [12]

(3a) Using the figure below (describing two weakly coupled Einstein oscillators A and B), give three arguments that lead to the definition of temperature as $T \equiv \left(\dfrac{\partial S}{\partial U}\right)^{-1}$. You must write down any relevant formulas. [6]



(3b) Can a system with a concave-up entropy-energy graph, ever be in stable thermal equilibrium with another system? Explain. The graph is shown in the
gure below. [2]

(3c) Use the expression for the entropy of a monoatomic ideal gas (see information sheet), to calculate the energy of this gas. Explain why the result is what you expect. [4]

END of QUESTIONS

INFORMATION SHEET

$R = 8.31 \dfrac{\mathrm{J}}{\mathrm{mol.K}}$; $N_A = 6.022 \times 10^{23}$ mol^{-1}

Boltzmann's constant: $k = \dfrac{R}{N_A} = 1.381 \times 10^{-23}$ J/K

Equipartition theorem: $U_{\text{per molecule}} = \dfrac{f}{2} kT$

$$C_V = \left(\frac{\partial U}{\partial T}\right)_V$$

$$C_P = \left(\frac{\partial U}{\partial T}\right)_P + P\left(\frac{\partial V}{\partial T}\right)_P$$

Adiabatic compression: $VT^{f/2} = \text{constant}$ and $V^\gamma P = \text{constant}$ where $\gamma = (f+2)/f$

Fourier heat conduction law: $\dfrac{Q}{\Delta t} = -k_t A \dfrac{dT}{dx}$

Two-state system multiplicity: $\Omega(N,n) = \dfrac{N!}{n! \cdot (N-n)!} = \dbinom{N}{n}$

Multiplicity of an Einstein solid: $\Omega(N,q) = \dfrac{(q+N-1)!}{q! \cdot (N-1)!} = \dbinom{q+N-1}{q}$

Multiplicity of a monoatomic ideal gas: $\Omega_N = \dfrac{1}{N!} \dfrac{V^N}{h^{3N}} \dfrac{\pi^{3N/2}}{(3N/2)!} (\sqrt{2mU})^{3N}$

Stirling's approximation: $N! \approx N^N e^{-N} \sqrt{2\pi N}$ and $\ln N! \approx N \ln N - N$

Approximate form of the Heisenberg uncertainty principle: $(\Delta x)(\Delta p_x) \gtrapprox h$

Sackur-Tetrode equation: $S = Nk \left[\ln\left(\dfrac{V}{N} \left(\dfrac{4\pi m U}{3Nh^2} \right)^{3/2} \right) + \dfrac{5}{2} \right]$

$c_V(\text{water}) = 4186$ J/kg.K

$$\frac{1}{T} \equiv \left(\frac{\partial S}{\partial U}\right)_{N,V}$$

$\sinh x = \frac{1}{2}(e^x - e^{-x})$; $\cosh x = \frac{1}{2}(e^x + e^{-x})$; $\tanh x = (\sinh x)/(\cosh x)$