SURNAME:____________________ INITIALS:____________________

STUDENT NUMBER:____

UNIVERSITY of JOHANNESBURG

Physics 2Y (PHY00Y2/PHY002Y) November Exam

Thermal Physics

	Student's mark	Questions' mark
Q1		**19**
Q2		**22**
Q3		**16**
Total		**57**

Date: 26 November 2019

Examiner: Mr L. Nyadzani

Moderator: Prof. E. Carleschi

Time: 115 Minutes

Pencils and cell-phones are not allowed.
Answer all the questions.
This paper consists of 9 pages including 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!!!

IF YOU NEED MORE SPACE WRITE ON THE BACK OF THE PAGE

Do not write in the margins

Question 1 [19]

1.1 The temperature of one substance is 80 degrees F and another substance is 30 degrees F. If they are placed close together, what will happen ? [2]

1.2 Suppose that a gas originally at standard temperature and pressure undergoes a change in which its pressure is quadrupled while its temperature is cut in half. What change in volume does the gas experience during this process?. [3]

1.3 For an ideal gas of one molecule in a smooth cylinder of volume V, with a piston at one end, the average pressure is given by: $\overline{P} = \frac{mv_x^2}{V}$, where v_x is the horizontal component of the velocity, i.e., in the direction towards the piston. From this derive an expression for the average translational kinetic energy of a large number of identical molecules and show that the root mean square of the average speed is given by [7]

$$v_{rms} = \sqrt{\frac{3kT}{m}}$$

.

1.4 Show that the work done during quasistatic compression is given by,

$$W = -\int_{V_i}^{V_f} P(V)\, dV.$$

If necessary use a drawing [5]

1.5 Write down the expression for enthalpy. Explain what the various contributions to the enthalpy are due to. [2]

Question 2 [22]

2.1 Suppose that you flip 20 fair coins.

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

(ii) What is the probability of getting the sequence HTHHTHHTTTHTHTTHTHHT (in exactly that order)? [1]

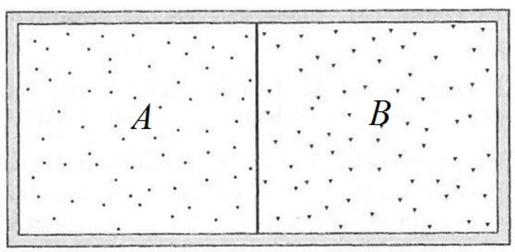
(iii) What is the probability of getting 12 heads and 8 tails (in any order)? [2]

2.2 An Einstein solid has four oscillators and two units of energy. Draw all the possible microstates. You must represent each microstate by a series of dots and vertical lines. Note: this is similar to what one does when proving the formula for the multiplicity of an Einstein solid. [3]

2.3 Derive a formula for the multiplicity of an Einstein solid containing a large number of oscillators and energy units, in the **low-temperature limit** ($q \ll N$). [8]

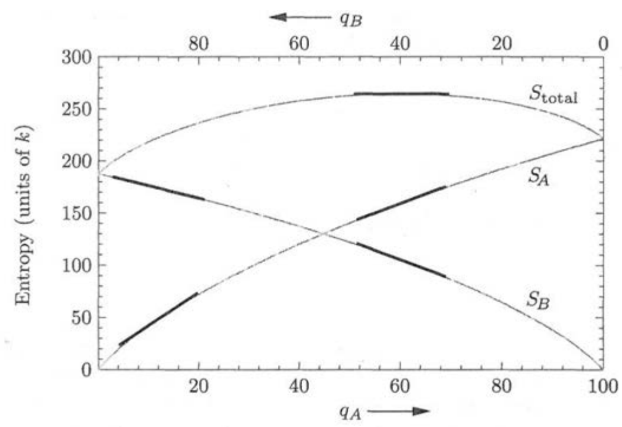
2.4 Explain, in your own words, why energy flows spontaneously from a hot object to a cold object. [3]

2.5 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]

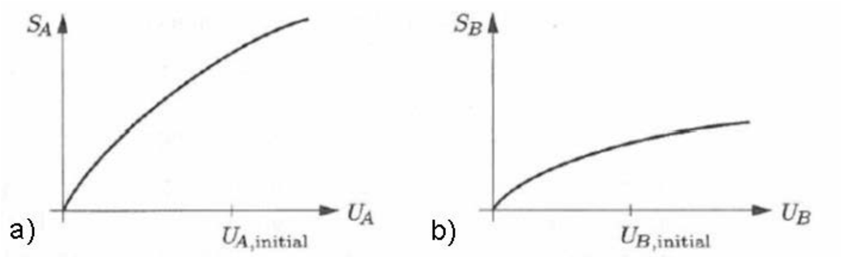


Question 3 [16]

3.1 Using the figure below (describing two weakly coupled Einstein oscillators A and B), give three arguments that lead to the definition of temperature as $T \equiv \left(\frac{\partial S}{\partial U}\right)^{-1}$ [6]



3.2 The two figures below show graphs of energy vs. entropy for two objects, A and B. Both graphs are on the same scale. The energies of these two objects initially have the values indicated.



(i) The objects are then brought into thermal contact with each other. Explain what happens and why, without using the word "temperature". [3]

(ii) Draw both graphs a) and b) on your script and indicate where you think the values of the energies will be once equilibrium is reached. [1]

3.3 Use the expression for the entropy of a monatomic ideal gas to calculate its temperature. Then show that this verifies the equipartition theorem. [6]

END of QUESTIONS

INFORMATION SHEET

$R = 8.31 \dfrac{\text{J}}{\text{mol.K}}$; $N_A = 6.022 \times 10^{23}$ mol^{-1} ; Atmospheric pressure $= 1.03{\times}10^5$ Pa

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: $\Omega(N,q) = \dfrac{(q+N-1)!}{q! \cdot (N-1)!} = \dbinom{q+N-1}{q}$

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: $S = Nk\left[\ln\left(\dfrac{V}{N}\left(\dfrac{4\pi mU}{3Nh^2}\right)^{3/2}\right) + \dfrac{5}{2}\right]$

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

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

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