Physics II
ISI B.Math
Final Exam : November 13, 2013

Total Marks: 50
Time: 3 hours
Answer question 1 and any 4 from the rest.

1. **(Marks : 5 × 2 = 10)**
For the following multiple choice questions indicate your answers by the appropriate letters (a), (b), (c) or (d).There is only one correct answer.

(i) Experiments were conducted by four different groups to measure the variation of the heat capacity at constant volume of a solid sample with temperature in the very low temperature regime. The results obtained are given in (a),(b), (c) and (d). Which of these results is compatible with the laws of thermodynamics?

(a) $C_V = \frac{a}{\sqrt{T}}$, where a is a constant.
(b) $C_V = \frac{3}{2}R$
(c) $C_V = aT^3$, where a is a constant.
(d) $C_V = a \ln T$ where a is a constant.

(ii) There are two insulated boxes A and B each of volume 2V. Both boxes are partitioned into equal halves of volume V by a removable partition. Box A contains N oxygen molecules in the left half and N nitrogen molecules in the right half at the same temperature and pressure. Box B contains N oxygen molecules in the left half and N oxygen molecules in the right half at the same temperature and pressure . When both partitions are removed,

(a) the entropy of both A and B increase
(b) The entropy of A increases but the entropy of B remains the same.
(c) The entropy of B increases but the entropy of A remains the same.
(d)The entropy of both A and B remain unchanged.

(iii) Which of the following statements referring to an ideal gas is false?

(a) The enthalpy of an ideal gas is independent of its volume.
(b) The temperature of a fixed mass of ideal gas decreases when it undergoes quasistatic adiabatic expansion
(c) The temperature of a fixed mass of ideal gas remains unchanged when it undergoes adiabatic free expansion
(d) The entropy of a fixed mass of ideal gas remains unchanged when it undergoes adiabatic free expansion.

(iv) If the width of each slit is decreased to half the original width in a double slit experiment, which of the following statements will be true ?

(a) The intensity of a bright fringe will be half the original intensity
(b) The intensity of a bright fringe will remain unaltered.

(c) The intensity of a bright fringe will be double the original intensity
(d) The intensity of a bright fringe will be one-fourth the original intensity
.
(v) If a double slit experiment is performed with white light, which of the following statements is false?

(a) The central fringe will be white.
(b)There will be no completely dark fringe.
(c) The fringe next to the central will be red
(d) The fringe next to the central will be violet.

2. **(Marks: 10)**

Take a gas whose equation of state is $P(V-b) = nR\theta$(where b is a constant and θ is the temperature) and whose heat capacity C_V is a function of θ only through a Carnot cycle and show that $\theta = T$, where T is the absolute temperature.

3.**(Marks: 3 + 4 + 3)**

Consider a system of N atoms with spin such that when placed in a magnetic field, the spin (or intrinsic magnetic moment) can align itself either parallel or antiparallel to the magnetic field. When the spin is aligned along the magnetic field the energy of the atom is $-\epsilon$ and when it is aligned opposite to the magnetic field the energy of the atom is ϵ.
i) Find the number of microstates Ω corresponding to a state of total energy E
ii) Find the entropy $S(N, E)$ of the system using the result in i). Since N is large, feel free to use Stirling's approximation for large N

$$\log N! \simeq N \log N - N$$

iii) Plot $S(N, E)$ as a function of E. Use the plot to show that this system can have a negative absolute temperature.

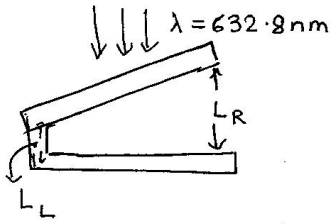
4. **(Marks = 10)**

Einstein introduced a simplified model of solids where a solid is a collection of independent quantum harmonic oscillators of the same angular frequency ω. The energy accessible to each oscillator is given by $E_n = (n + \frac{1}{2})\hbar\omega$, where $n = 0, 1, 2, 3 \cdots$. One mole of the solid therefore contains $3N_a$ independent one-dimensional harmonic oscillators where N_a is Avogadro's number. Using the partition function show that the molar specific heat of the solid based on Einstein's model is given by:

$$C_V = 3R \left(\frac{\theta_E}{T}\right)^2 \frac{e^{\frac{\theta_E}{T}}}{(e^{\frac{\theta_E}{T}} - 1)^2}$$

where T is the absolute temperature, $R = N_a k$ and $\frac{\hbar\omega}{kT} = \frac{\theta_E}{T}$.
Obtain the limiting forms of the specific heat for $T \gg \theta_E$ and $T \ll \theta_E$. Is the low temperature behaviour consistent with the third law of thermodynamics?

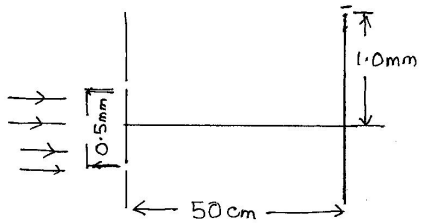
5. **(Marks = 6 + 4)**



(a) The figure shows a transparent plastic block with a thin wedge of air . A broad beam of red light with wavelength $\lambda = 632.8$ nm is directed downward through the top of the block. Some of the light is reflected back up from the top and bottom surfaces of the wedge, which acts as a thin film of air with a thickness that varies uniformly and gradually from L_L at the left to L_R at the right. An observer looking down at the wedge sees an interference pattern consisting of six dark fringes and five bright red fringes along the wedge. What is the change in thickness $\Delta L = (L_R - L_L)$ along the wedge?

(b) A thin film 4×10^{-5} cm thick is illuminated by white light normal to its surface and its index of refraction is 1.5. What wavelengths within the visible spectrum $(400 - -700\text{nm})$ will be intensely seen in the reflected beam ?

6. **(Marks = 5 + 5)**



White coherent light(400nm -700nm) is sent through the slits of a Young's double slit experiment. The separation between the slits is 0.5 mm and the screen is 50 cm away from the slits. There is a hole in the screen at a point 1.0 mm away(along the width of the fringes) from the central line.
(a) Which wavelength(s) will be absent in the light coming through the hole ?
(b) Which wavelength(s) will have a strong intensity ?

7. **(Marks = 5 + 3 + 2)**

(a) Consider Fraunhofer diffraction by a single slit of width a illuminated by coherent light of wavelength λ. Calculate approximately, the relative intensities $\frac{I_\theta}{I_m}$ (I_θ and I_m are respectively the intensity of light diffracted at an angle θ and the maximum intensity) of the secondary maxima. You may use the approximation that the secondary maxima lie approximately halfway between the minima.
(b) Consider a double slit arrangement with each slit of width b and the separation between slits equal to d. Derive an expression for the number of interference maxima occurring under the central diffraction minimum of the double slit pattern in terms of d and b.
(c) Explain why in a grating made out of alternate transparent and opaque strips of equal width all the even order interference maxima (excluding $m = 0$) are absent.