**University of Louisville**
**College of Arts and Sciences**

# Department of Physics and Astronomy PhD Qualifying Examination (Part I)

# Fall 2014

*Paper C – Thermal Physics*

Time allowed – 90 minutes

**Instructions and Information:**

- Answer both questions
- This is a closed book examination
- Start each question on a new sheet of paper – use only one side of each sheet
- Write your identification number on the upper right hand corner of each answer sheet
- You may use a non programmable calculator
- Partial credit will be awarded.
- Correct answers without adequate explanations will not receive full credit.
- Make sure your work is legible and clear
- The points assigned to each part of each question is clearly indicated

## Thermal Physics Basic

A steel ball bearing, radius 2 cm, volume $2.5 \times 10^{-5}$ $m^3$, initially at 4 $^0$C is dropped into a tank containing 2.5 kg of liquid Nitrogen initially at 73 K. The equilibrium temperature is exactly the boiling point of liquid Nitrogen ( 77 K ), but none of the liquid Nitrogen boils away. (Latent heat of vaporization of Nitrogen = 200,000 J/kg; specific heat of liquid nitrogen = 2000 J/kg.K; specific heat of steel = 500 J/kg.K; specific heat of Nitrogen gas = 750 J/kg.K; 0 $^0$C = 273 K ).

***In all situations you should assume that no heat is gained or lost from the surroundings***.

(a) How many joules of heat are released when the temperature of 1 kg of steel drops by 1 $^0$C ? (2)

(b) Determine the mass of the ball bearing. (8)

(c) If the volume coefficient of thermal expansion of steel is $36 \times 10^{-6}$ $K^{-1}$, calculate the change in volume of the ball bearing. (7)

(d) Determine the change in the radius of the ball bearing. (7)

(e) A second steel ball bearing, mass 5 kg, is dropped into a different tank containing the same mass of liquid Nitrogen at the same initial temperature (73K). Determine the equilibrium temperature in this case. (11)

## Thermal Physics Intermediate

The statistics of paramagnetism can be studied using a model system of N identical, localized, non-interacting magnetic dipoles, each with a dipole moment of m, in a uniform applied magnetic field H. We consider here the case of classical dipoles that can be oriented in any direction relative to the applied field. In such a case, the total energy of the system can be written as

$$E = \sum_{i=1}^{N} E_i = -\sum_{i=1}^{N} \vec{\mu}_i \cdot \vec{H} = -\mu H \sum_{i=1}^{N} \cos\theta_i$$

Assume the applied magnetic field is in the positive z direction, the angle $\theta_i$ would be the angle between the magnetic moment of the i-th dipole and the z axis.

(a) Calculate the partition function of the system at a given temperature T. (25)

(b) Calculate the mean magnetic moment of the system. (20)

(c) Show that in the high temperature limit, $\frac{k_B T}{\mu H} \gg 1$, the mean magnetic moment of the whole system is approximately $CN\frac{H}{T}$ $(this\ is\ the\ so-called\ Curie\ law)$, and find the constant C. (20)