Final Exam for Physics 4052, Spring 2007

100 points - closed book – calculators allowed - show your work – 3 hours

Instructions: Solve any 4 of the 5 problems below. Each problem is 25 points. Start each problem in a different page. Write clearly and neatly with a pencil (not a pen). Use an eraser. State your assumptions clearly. Use words if necessary.

Calculators are allowed but formula sheets or other aides are not allowed.

1. The net radiation exchange between two grey surfaces labeled 1, 2 is given by

\[ q = \frac{\sigma (T_1^4 - T_2^4)}{(1 - \varepsilon_1) + \frac{1}{A_{F_{12}}} \frac{(1 - \varepsilon_2)}{\varepsilon_2 A_2}}, \]

where \( A_i \), \( \varepsilon_i \), and \( T_i \) are the area, emissivity, and temperature of the surfaces (i=1,2), respectively. The value for the Stefan Boltzmann constant, \( \sigma \), is \( 5.670 \times 10^{-8} \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4} \).

Consider a small sphere labeled 1 that is placed in a much larger room labeled 2. In this limit find an expression for \( q \). How would \( q \) change if \( \varepsilon_2 \) was doubled or halved, or if \( A_2 \) increased even more?

2. You are designing a liquid helium cryostat. Your initial design consists of three aluminum concentric cylinders. The outermost one is at 300 K the middle one is a radiation shield and the inner one is held at 4 K. The corresponding radii \( r_1, r_3, \) and \( r_2 \) are 10 cm, 6 cm, and 3 cm, respectively. The emissivities of all the shells are \( \varepsilon=0.02 \) and they are 100 cm long. The inner shells are suspended relative to the 300 K shell by means of hypothetical rigid contacts that have negligible thermal conductance. Neglect the heat load due to the top and bottom circular plates that close the cryostat. Calculate the temperature of the radiation shield.
3. Give a 2-5 sentence written answer to each of the following questions.

a) At what wavelength can one begin to resolve single photons with a room temperature detector? Provide a physical argument why this is the case. What frequency band is this? You may find the following constants useful: \( h = 4.13 \times 10^{-15} \text{ eV*s}, k_B = 8.6 \times 10^{-5} \text{ eV/K}. \)

b) Is the following statement correct or incorrect “The specific heat of all materials at high temperature is the same and is inversely proportional to the cube of the Debye temperature, which is a universal constant”? Explain your answer.

c) Describe how the heterodyning process works and why a non-linear circuit element is required. You may find the following trig identity useful:

\[
\cos(\omega_1 t)\cos(\omega_2 t) = \frac{1}{2} \cos(\omega_1 + \omega_2) + \frac{1}{2} \cos(\omega_1 - \omega_2)
\]

d) What are the two important parameters when discussing gas flow regimes in vacuum systems? What are the different flow regimes as a function of the ratio of these parameters?

4. Consider a 10-stage photomultiplier tube with an S-20 photocathode.

a) If each photoelectron produces a charge of 0.21 pC at the anode, what is the average secondary emission coefficient (\( \delta \)), assuming 100% collection efficiency? (Recall that \( 6.24 \times 10^{18} \text{ electrons} = 1 \text{C} \))
b) Suppose we observe a current of 85 nA at the output of the PMT when the PMT is illuminated by a light source emitting at 650 nm. How many photons are hitting the photocathode on average each second? (Use the QE chart above.)

c) When installed in an apparatus, the PMT experiences thermal cycling from 15°C to 45°C and back again over a day/night cycle. The PMT is observed to produce significantly more noise pulses during the day than at night: a factor of 30 times more pulses. Determine the effective energy barrier for dark-count electron emission. (Recall that the Boltzmann coefficient is $8.62 \times 10^{-5}$ eV/K)

5. The 2000 Particle Data Tables contained the following experimental measurements of the mean lifetime of the $K_s$ meson. Find the weighted mean of the measurements and the uncertainty in the mean.

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<tbody>
<tr>
<td>1</td>
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