Nuclear Chemistry Cumulative Examination
Wednesday, 18 November 2o15

This examination consists of twenty questions on general information and properties of radiation detectors. The exam has a total of 100 points.

Some constants: q_e 1.602x10^{-19} Coul, ϵ_0 8.854x10^{-12} F/m
h 6.626x10^{-34} J-s, Aluminum mass density 2.70 g/cm^3, c 299 792 458 m/s

1. (20 points) The Environmental Health and Safety group at MSU uses two types of Ludlum survey meters that are used to check for radioactive spills in laboratories. One device uses a 2 inch diameter by 2 inch long cylindrical NaI(Tl) crystal (Ludlum #44-10) and the other, called a pancake detector, uses a Geiger-Mueller counter that is 2 inch in diameter and is 0.5 inch deep. The background counting rates of the two detectors when sitting next to each other in a hallway counting background radiation were 2000 counts/min and 60 counts/min, respectively.
   Give the most plausible explanation for the very large difference in the observed counting rates in these two devices under identical conditions.

2. (20 points, 5 each) Provide **concise** and accurate answers to the following four general questions about the properties of scintillation detectors.
   (a) Inorganic scintillators are all insulators and some have activators. The most common example is NaI(Tl). What is the mechanism of scintillation light production in this material?
   (b) The reference organic scintillator is stilbene for historical reasons and has a light output close to that of NaI(Tl). Approximately how many photons are produced by these scintillators for each MeV of energy deposited by ionizing radiation? Getting the order of magnitude correct is acceptable.
   (c) What is the only significant difference between liquid and solid organic scintillators?
   (d) What is the difference between fluorescence and phosphorescence in an organic scintillator?

3. (20 points, 5 points each) Provide **concise** and accurate answers to the following five general questions about the properties of photomulitplier tubes that are necessary to operate scintillation detectors.
   (a) If the gain of an eight stage PMT is 65536 (2^{16}), what is the value of δ for dynodes in this tube under these conditions?

(b) Make an estimate of the quantum efficiency of a typical PMT that uses a Bi-alkali photocathode for visible light. An acceptable answer should be within a factor of two of the real number.

(c) A PMT requires a voltage divider made up of resistors to operate. The resistor chain should have so-called bypass capacitors for the dynodes closest to the anode, what is the reason for these capacitors?

(d) A PMT that is operated with positive high voltage is said to be "AC coupled". What does this imply about the electrical connection to the anode?

4. (20 points) Ortec sells a Hyperpure germanium (HPGe) detector that is called a 130% detector. The device has a closed-end geometry and is operated with a positive bias of 2500 V.

   (a) (5 points) What does the efficiency value of 130% refer to? That is, how can the efficiency be larger that 100%?

   (b) (5 points) Assuming that this device consists of n-type germanium, which charge carriers are collected on the central contact of the detector?

   (c) (5 points) Assume that a 1.0 MeV gamma ray enters this HPGe detector and the full energy is absorbed after only two interactions. What is the most likely sequence of these two interactions (in time order) in the crystal that led to the full energy absorption.

   (d) (5 points) Describe the difference between true coincidence summing and random summing as those terms are used in gamma-ray spectroscopy.

5. (20 points) The SuN device is a γ-ray Total Absorption Spectrometer. It is a cylindrical shaped NaI(Tl) detector, 16-inch in diameter and 16-inch long with a 45 mm [1.8 inch diameter] borehole along its axis. It is segmented in 8 optically separated segments, which are positioned above and below the beam axis. Each segment is being read by three photomultiplier tubes resulting in a total of 24 signals coming out of the detector. The total efficiency of SuN for a ^{137}Cs source placed at the exact center of the device (E_γ = 661 keV) is 85%. For the summing of the two sequential γ-rays from the decay of ^{60}Co the sum-peak total efficiency is 65%.

   (a) (5 points) Make an estimate of the geometrical efficiency for a gamma-ray point source that is positioned exactly in the middle of the bore tube and the middle of the device. Show your work!

   (b) (5 points) Use your estimate of the geometrical efficiency and their statement about the total efficiency to calculate the intrinsic efficiency of the device for the ^{137}Cs gamma ray.

(c) (10 points) The spectrum shown below was obtained with a ^{60}Co source placed in exactly the middle of the SuN detector. Describe the physical phenomena that create the features labeled A through E in the figure. In case you don't recall, ^{40}K is a naturally occurring radioisotope that emits a beta particle and then a gamma ray (1462 keV).