Nuclear Chemistry Cumulative Examination
Wednesday, 25 January 2o12

This examination is concerned with the general properties of radiation detectors and related equipment as discussed in Chem-985 and the textbook Radiation Detection and Measurement by Knoll.

The exam has a total of 90 points.

1. (20 points, 5 points each) Give a concise and accurate answer to each of the following short questions about gas-filled nuclear radiation detectors.

   (a) Explain why gas-filled proportional chambers tend to be constructed with a very thin central wire (perhaps 40μm in diameter) and often have a cylindrical geometry.

   (b) Which fill gas would you expect to give a larger gain in a gas proportional counter, pure helium or a mixture of helium and a small amount of argon, all other things being equal? Explain your answer.

   (c) A Geiger counter is closely related to a gas-filled proportional counter but is generally operated with the Ar/Methane gas mixture commonly called P-10 and not with a He/Ar mixture. Why is methane needed in a Geiger counter and not Argon?

   (d) The so-called ion chambers used at the NSCL are often really proportional chambers. Explain why the filling gas (the active ingredient) in these devices has to be flowed through the chamber (at a low rate) in order to ensure reproducible operation during the course of a three-day long experiment.

2. (25 points, 5 points each) Give a concise and accurate answer to each of the following short questions about photomultiplier tubes (PMT) that are used extensively in nuclear radiation detectors.

   (a) What is the definition of the quantum efficiency, η, of a PMT and give a typical vaule of η for a modern PMT in the visible region.

   (b) The dynodes of a PMT are described by a coefficient δ. Give a definition of this coefficient and a typical value for the dynodes in a modern PMT.

   (c) What is the most important parameter of the **window** of a PMT that must be matched to the properties of a given scintillator to ensure maximum efficiency of the whole detector?

   (d) All PMT's need to be connected to a "base" to operate. What is the difference between a so-called "active base" and a "passive base" for a a photomultiplier tube?

(e) The Department of Homeland Security has made a big push to replace their "Portal Monitors" used to screen cargo containers and trucks that rely on plastic scintillators connected to PMT's with some other scintillation material in order to perform **spectroscopic identification** of radioactivities. Explain why the present portal monitors are not good for spectroscopy and indicate the important properties of another scintillator that would make a better portal monitor.

3. (25 points, 5 points each) Give a concise and accurate answer to each of the following short questions related to radiation detectors that use germanium diodes.

   (a) The preferred material for gamma-ray detectors used in nuclear reaction studies is n-type germanium. Describe the most likely damage mechanism to the germanium crystals used in nuclear reaction studies, the way to repair this damage, and why vacuum is applied to the detector during the repair process.

   (b) The central contact n-type germanium detectors in segmented devices is connected to high voltage while the other contacts are at ground potential. What charge carriers are collected on the central contact and what is the expected polarity of the output signal? Is this signal AC or DC coupled?

   (c) Describe the geometry of a true-coaxial germanium detector and an end-cap germanium detector and clearly indicate the most significant differences between the two geometries.

   (d) "Wilkinson ADC's" presently provide the highest resolution for signal processing in nuclear spectrosopy. Describe the basic operation of a "Wilkinson" ADC.

   (e) Give separate reasons for using: (a) the shortest possible connection between a radiation detector and its preamp, and (b) for using a twisted-pair connection between the preamp and the next stage of the signal processing system?

4. (10 points) Make an accurate sketch of the features that would be present in a pulse-height spectrum obtained from a small inorganic scintillation crystal in a close-fitting lead shield that is thick enough to absorb external background radiation. The device is used to measure the potassium content of various materials via the decay of naturally occurring ^{40}K. This nuclide decays by β^- emission to an excited state in the daughter, the daughter promptly decays by the emission of a 1461 keV photon. Indicate all of the features you expect to be present in the spectrum.

5. (10 points) A gamma-ray detector in use at the NSCL has a photopeak efficiency of 75%. What is the expected counting rate for the 0.662 MeV peak from a 10μCi ^{137}Cs point source at a distance of 50 cm from one of these detectors?