Chemistry 985

Fall, 2o15 | Exam # 2 **Take Home**
Distributed: Mon., 7 Dec. 15, 12:30PM | Due: 9 Dec. 15, 1:30PM

Please work independently and show work for full credit.
This exam has five pages.

1. Give a concise and accurate answer to each of the following short questions about gas-filled nuclear radiation detectors.

   (a) (4 points) 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.

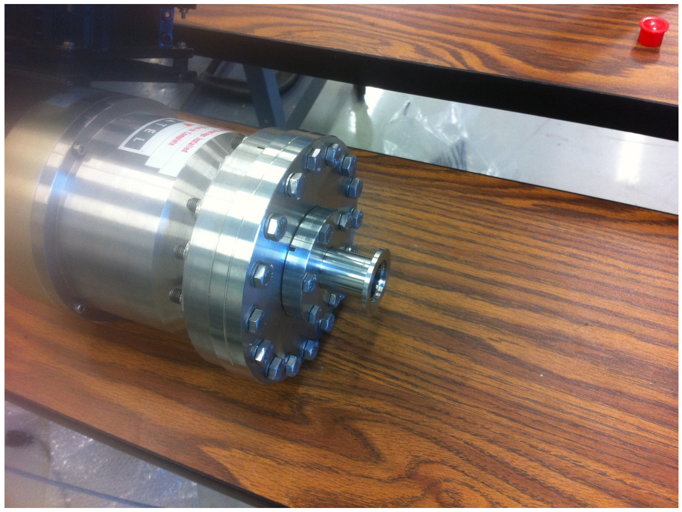
   (b) (3 points) A Geiger counter is closely related to a gas-filled proportional counter but is generally operated with the Ar/Methane gas mixture commonly called P-10 and not with a He/Ar mixture. Why is methane needed in a Geiger counter and not Argon?

   (c) (3 points) The so-called ion chambers used at the NSCL are almost all really proportional chambers. Explain why a typical fill-gas such as P-10 or CF_4 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. This question refers to the photograph shown below of a piece of vacuum equipment recently photographed at the NSCL. Note that this pump has a list price of more than $10k.

   (a) (10 points) Estimate the pumping speed of this whole apparatus for nitrogen if the pump is an Alcatel 250 L/s TMP that is connected to (1) a conflat 6-inch to 2.75-inch "zero length" adapter and then to (2) a 2.75-inch to KF-25 adapter in the center of the 6-inch conflat adapter flange.

   (b) (5 points) Indicate a reason based on TMP design and operation that is it unlikely that the pumping speed of this configuration will be as high as calculated in part (a).



3. Provide **concise** and accurate answers to the following five general questions about the properties of photomulitplier tubes and scintillation detectors.

   (a) (5 points) What is the only significant difference between liquid and solid organic scintillators?

   (b) (5 points) Indicate any differences between fluorescence and phosphorescence light in an organic scintillator?

   (c) (5 points) As you know, a PMT requires a voltage divider made up of resistors to operate. The resistor chain in a passive base should have so-called bypass capacitors for the dynodes closest to the anode, what is the reason for these capacitors?

   (d) (5 points) Assume that a 1.0 MeV gamma ray enters a scintillation detector and the full energy is absorbed after only two interactions. Describe the interactions and what is the most likely sequence of these two interactions (in time order) in the crystal that would lead to the full energy absorption.

   (e) (5 points) Explain why true coincident summing is usually present in measurements of gamma-ray decay but sometimes is impossible.

4. Answer the following four questions about an ADC that was described in a recent advertisement (page 55 of **Physics Today**, November 2015). Some of the "Features of the device" were: High speed ADC (100

MHz, 16 bit), data output in 8k data channels, Conversion time 10 ns, Sliding-scale linearization, Differential nonlinearity $< \pm 0.6\%$, Integral nonlinearity $< \pm 0.02\%$, etc.

(a) (5 points) Describe the "sliding scale lineariztion" concept and what it is designed to compensate. Given the information in the advertisement, what is the *exact* number of valid channels in the output spectrum?

(b) (5 points) The conversion time that they quote does not seem to correspond to the usual definition but rather to the clock speed. What is the minimum conversion time of a pulse at half-full-scale if this device uses a successive approximation algorithm (one comparitor) at this clock speed?

(c) (5 points) What is the minimum conversion time of a pulse at half-full-scale if this device uses a Wilkinson algorithm (one comparitor) at this clock speed?

(d) (5 points) What is the expected resolution (FWHM in percent) for a test pulse (much narrower than V_{LSB}) at half-full-scale based on this information?

5. The following questions (a to f) refer to some data in another advertisement, part of which is shown below, for a detector system to monitor pedestrians. The advertisement is mostly about the software but the system is based on a 3"x3" NaI(Tl) detector with a PMT attached to a combined shaping amplifier with MCA connected by USB to a computer. They provide a graph of the interaction probability for their detector, a typical spectrum from the MCA and most importantly the results for detecting a surreptitious radioactive source for the perspicacious buyer. Notice that only the "Total Counts" are shown as a function of time (without uncertainties) and I assume the total counts are the sum of the number of counts in the spectrum obtained at each time interval.

   (a) (5 points) What is the expected total counting rate in this detector for the radioactive source carried by the pedestrian under the specified conditions and provided data? The source is physically small compared to the distances mentioned and unshielded.

(b) (5 points) What is the expected resolution for this system for the 1332 keV gamma ray from ^{60}Co based on the information in the spectrum provided?

(c) (4 points) What is the observed number of counts due to the source in the reported measurement? Based on your calculation in the previous part, how long was the duration of each measurement as the pedestrian walked by?

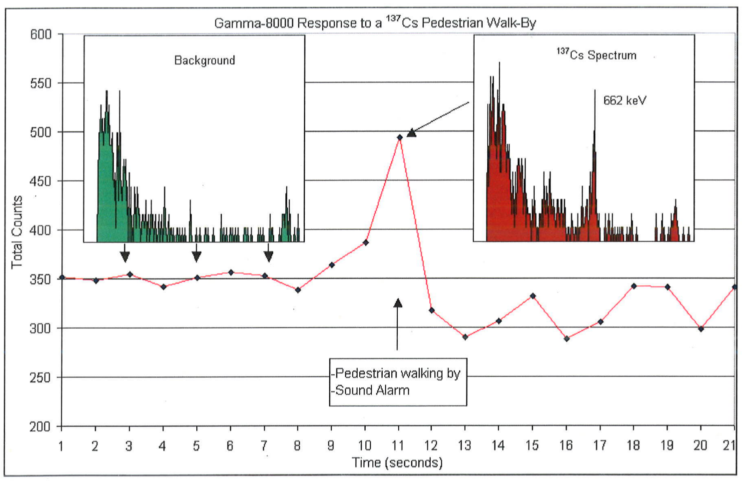
(d) (6 points) The reported data looks slightly suspicious because the distribution of "background" total counts before and after the walk-by appear different. (1) Make an estimate of the average variation in the reported background data before the event (time = 1 to 8 seconds), (2) make an estimate of the average variation in the reported data after the event (time = 13 to 20 seconds), and (3) make an estimate in the uncertainty of a true statistical distribution of the observed number of counts.

(e) (2 points) The typical spectrum from the manufacturer shows a peak at 32 keV. What is this due to and why is it not visible in the walk-by spectrum? (Be as specific as possible given all of the information.)

(f) (8 points) One of the really big problems with putting these systems into the hands of untrained security personnel is that there are a large number of people that get substantial doses of radioactive isotopes for medical procedures who are released into the public. For example, ^{131}I is used to treat thyroid cancer, a gland in the throat. Typically 4.0 mCi (yes millicuries) of the nuclide is given to the patient in the form of NaI (ironic, eh?) and the iodine is concentrated in the thyroid. Estimate the total number of counts expected in this detector system under the identical conditions if a person received this treatment one week prior to their walk-by. You can assume that the entire source was concentrated in the thyroid, stayed there, thus acted like a point source and was unshielded due to being in the throat. (Note that in real life some of the activity will be excreted before it decays.)

Pedestrian Monitoring System for Radioactive Materials (GAMMA-8000 76 x 76 mm NaI)
Homeland Security Application

Example of a pedestrian walking 10 ft away from a monitoring station and carrying a 100 μC ^{137}Cs radioactive source. This type of event could not have been detected with a standard Geiger counter since it registered a natural background of 0.02 mR/hr before and during the pedestrian incident. However, as shown in the figure below, the GAMMA-8000 quickly detected a rise in the Total Counts in order to sound the alarm, and unlike the Geiger counter, recorded the spectral information separately for every second. Hence, positive identification of the ^{137}Cs isotope was made by identifying the 662 keV peak.



NaI(Tl) Efficiency

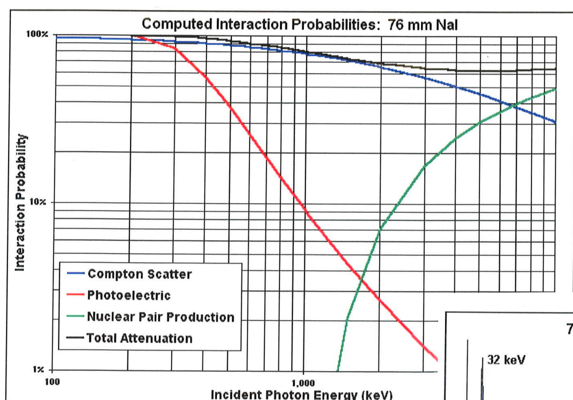


Figure 6.

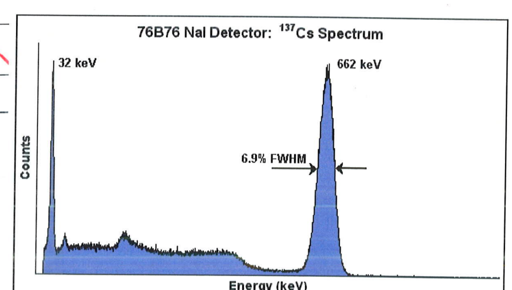


Figure 2. ^{137}Cs Spectrum.