Chemistry 985

Fall, 2o19 — Problem Set #3

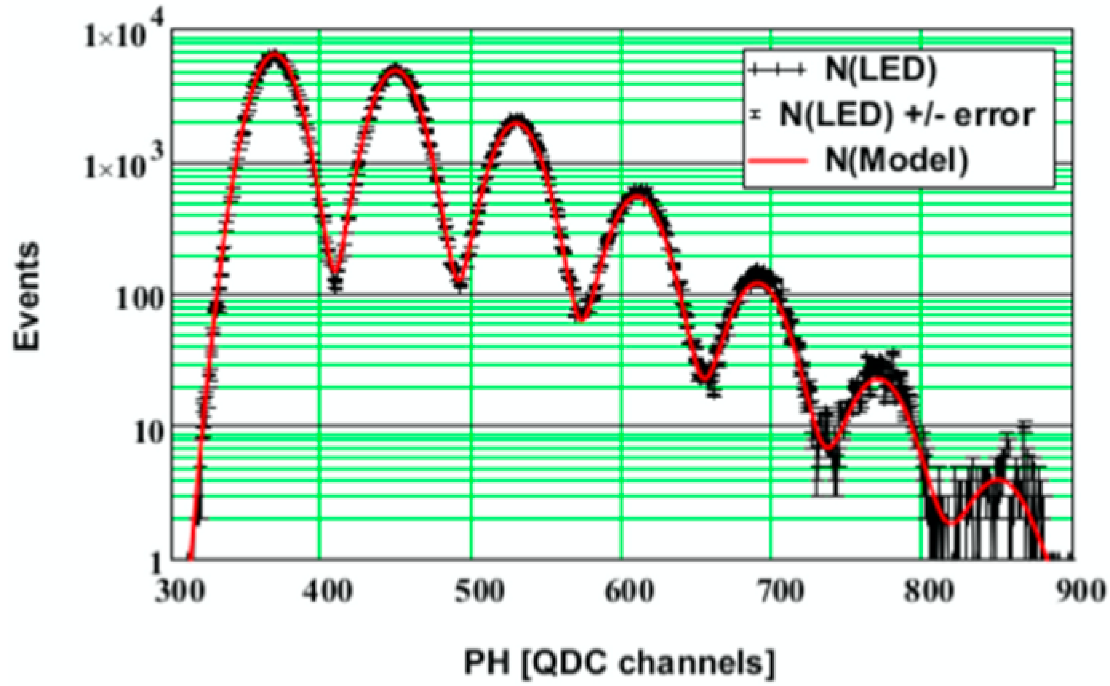
Distributed: Tues., 22 Oct. 2019 — Due: Thurs., 31 Oct. 2019

Show your work! Indicate sources of external data!

1. PMTs:
$^{54}$Mn is another relatively long-lived nuisance radioactivity that is created in stainless steel and other high iron-content materials that are hit by beams from the K1200 cyclotron. For practice, you should be able to show that the only gamma ray emitted by this source is 834.848 keV (99.976% intensity). A sample of irradiated material was measured with a 3"x3" (7.62 cm x 7.62 cm) right cylindrical NaI(Tl) detector at a distance of 10.0 cm. [Cf. Figure 10.29 for the intrinsic photopeak efficiency of such a device]. Going back to the original literature on these photopeak measurements I found that one of the data points in this figure was obtained with a $^{54}$Mn source and, more importantly, the PMT was an RCA-8054 which has a 10 stage structure with a gain of 1.6x10$^5$ with a 2000 kV bias that provides 68 mA/W at about 450 nm. The PMT is AC coupled through a 20 $\mu$F capacitor.

   (a) Give a plausible explanation for the differences seen in Figure 10.29 at this energy if the two detectors have identical light collection and PMT's. N.B., the photofraction (intrinsic photopeak efficiency) is not the light output.
   (b) What is the average value of $\delta$ for the dynodes in this tube?
   (c) What is the value of the quantum efficiency, $\eta$, of this tube?
   (d) What is the average number of photons produced in the crystal by this gamma ray?
   (e) What is the average number of photoelectrons produced in the tube by this gamma ray if only 80% are transmitted to the photocathode?
   (f) What is the expected size in volts of the average anode signal on the output capacitor from this gamma ray?

2. SiPM ?:
The figure below shows the result of measurements of the response of a commercial SiPM when exposed to individual photons [NIM **A854**(2017)70]. The data are the black crosses and their response function is shown by the red line. Analyze the data to show that the mean number of incident photons was one. Hint: Assume that this is essentially the full distribution (no signals above PH=900), obtain a normalized set of peak probabilities, graphically compare to model distributions to obtain the mean.



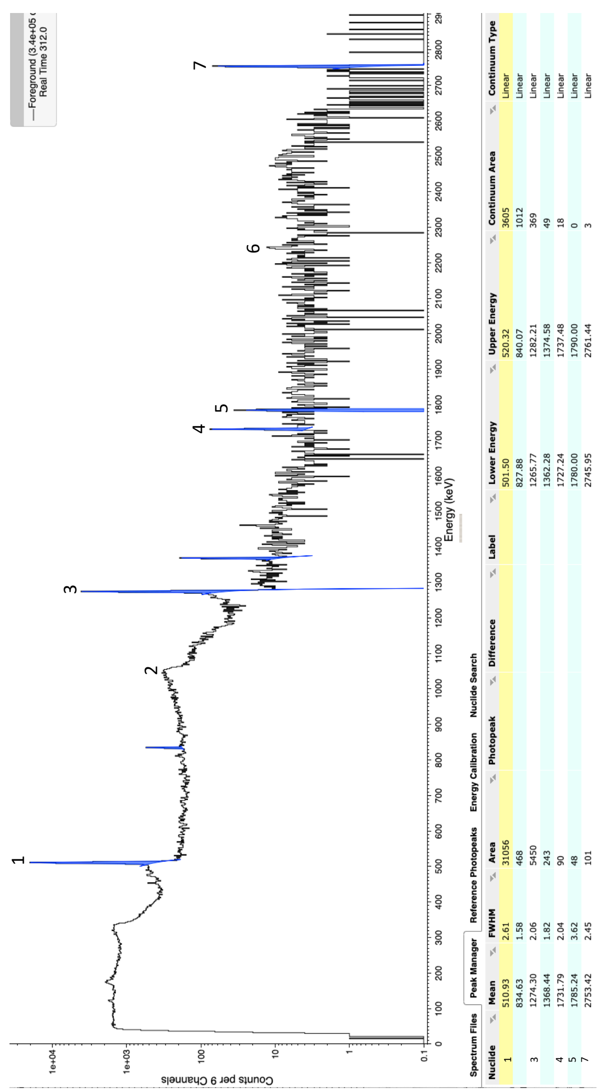

3. Silicon Diodes:
   The four-quadrant silicon PIN detector that was passed around class for viewing was labeled as 480 $\mu$m thick and an operating voltage of 57.1 V. The area of the detector was 5x5cm$^2$ and the surface roughness is about 1$\mu$m (front and back) for the wafer (i.e., an uncertainty of the thickness of $\pm2\mu$m). The dielectric constant of silicon is 11.9, the bulk is n-type, the implanted contacts are 0.5$\mu$m thick on each side, and it has a leakage current of 0.125 $\mu$A per quandrant under bias. The voltage is supplied to the unsegmented side by a power supply that has a 10 M$\Omega$ resistor in series with the detector with a dial to set the voltage and a sensitive current meter.

   (a) Estimate the resistivity of the bulk intrinsic material if the specified voltage fully (and exactly) depletes the intrinsic silicon.

   (b) What is the value of the voltage that should be set on the bias supply dial to obtain the depletion voltage at the detector? The schematic electrical bias circuit show in Figure 12.2 for a Ge PIN diode would be the applicable for a Si PIN diode. Hint: the detector has a finite resistance.

   (c) Use the nomogram in the text (Figure 11.10) to find the specific capacitance for this device and the *predicted* depletion depth for this device. What is the predicted capacitance of this device?

4. Gamma-ray Spectra:
   The figure shown below represents a high resolution gamma-ray spectrum of a radioactive part from the NSCL beam line. Identify the most likely mechanism to create each of the *seven features* labeled 1 to 7 in the spectrum. For reference the results of fitting Gaussian functions to some of the sharp peaks are given at the bottom of the figure with the corresponding labels. For your amusement I could point out that there are only two prominent radioactivities present plus a third weak component (mentioned in Problem 1).




| Nuclide | Mean | FWHM | Area | Photopeak | Difference | Label | Lower Energy | Upper Energy | Continuum Area | Continuum Type |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 510.93 | 2.61 | 31056 | | | | 501.50 | 520.32 | 3605 | Linear |
| | 834.63 | 1.58 | 468 | | | | 827.88 | 840.07 | 1012 | Linear |
| 3 | 1274.30 | 2.06 | 5450 | | | | 1265.77 | 1282.21 | 369 | Linear |
| | 1368.44 | 1.82 | 243 | | | | 1362.28 | 1374.58 | 49 | Linear |
| 4 | 1731.79 | 2.04 | 90 | | | | 1727.24 | 1737.48 | 18 | Linear |
| 5 | 1785.24 | 3.62 | 48 | | | | 1780.00 | 1790.00 | 0 | Linear |
| 7 | 2753.42 | 2.45 | 101 | | | | 2745.95 | 2761.44 | 3 | Linear |