Chemistry 985

Fall, 2o19 — Problem Set #2

Distributed: Thurs., 17 Sept. 2019 — Due: Thurs., 26 Sept. 2019

Show your work! Indicate sources of external data!

1. Statistics and Time Distributions

   (a) This class has 19 students this year with 16 Physics majors and 3 Chemistry majors. Imagine that a subset of three people is selected from the class at random to work on a special project. What is the probability that there are two Chemistry majors in this group using the binomial distribution? What is the variance of this probability?

   (b) A search for isotopes of fluorine (Z = 9), neon (Z = 10) and sodium (Z = 11) was recently conducted using the fragmentation of a ^{48}Ca beam at 345 MeV/nucleon and the BigRIPS separator at the Radioactive Isotope Beam Factory (RIBF) in Japan. One conclusion by the researchers is that the most neutron rich isotope of fluorine is ^{31}F since 3938 events were observed for it during a 14.0 hour run and no events of any heavier fluorine isotopes were observed. Notes: (1) ^{32}F is odd-odd and not bound, (2) that the cross section and thus the production rate for ^{33}F is unknown so the experimenters could only estimate the expected number of events. Their estimate for ^{33}F was 39 events if the cross section drops by an order of magnitude for each neutron at the drip line (this is rather conservative for such neutron-rich nuclei). Using Poisson statistics, what is probability that the experiment could run for 14.0 hours and not observe even one of the expected 39 events? Reestimate the Poisson probability if the production estimate is wrong and the "real" number of events was 4.

   (c) We considered the concept that the beam delivered by accelerators using radio frequency electrodes is not uniform in time. In fact, there are two relevant times scales called the microstructure (with a time constant $=1/f_{RF}$) and the macrostructure or duty factor that measures the fraction of time that the RF is turned on. At the NSCL the duty factor for the cyclotrons is 100% but for the reaccelerator it tends to be 10% or less. The experiment running on the reaccelerator last week used a proton beam at with a current 20 nA and a duty factor of 10%. What is the mean time between the arrival of beam particles during this run if we ignore the microstructure?

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2. Resolution
   The nuclear reaction products in many experiments at the NSCL are observed and identified by measuring the amount of ionization created as the particles cross an active layer of sensitive material. Later we will see that this layer could consist of a gaseous, a semiconductor material, or a solid material. Solid silicon is popular but has some drawbacks that we will consider later. The "w" for silicon is 3.5 eV and only slightly larger than the value of the band gap.

   (a) The fluorine particles mentioned in the previous problem had a kinetic energy of 244.7 MeV/u (magnetic rigidity of 8.804 Tm) and were detected in silicon material that was 450μm thick. The expected energy loss is 27.3 MeV. What is the expected resolution of this signal based solely on the calculated energy loss?
   (b) Most detector materials have a surface roughness of 1 μm unless they are highly polished. What is the expected resolution in this signal if the surface roughness contributes an uncertainty to the path length in the silicon of $\pm 2\mu$m?
   (c) Finally, the calculated straggling of these ions in silicon is significant being 0.9 MeV for each ion. What is the expected resolution including straggling and thickness variations (as independent processes)?

3. Efficiency:
   ^{51}Cr is a nuisance radioactivity that is copiously 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 320.08 keV (9.91% intensity). A *small* piece of metal was directly struck by the beam inside the K1200 cyclotron by mistake. A measurement with a particular detector found the part emitting 7.31 of these gamma's per second during a measurement made 13.0 days after the accident.

   (a) What is the corrected photon counting rate in the detector if the intrinsic efficiency of the detector was 2.4x10^{-2} for this transition and the (non-paralyzable) system dead time was 1.0 μs?
   (b) Estimate the actual decay rate for this transition if the detector had a circular active area with a 2.00 cm diameter and was placed 75.0 cm from the source. You can assume that the part appeared to be a "point source" in this geometry.
   (c) What is the ^{51}Cr activity in this piece of metal in Ci at the time of the accident?