Chemistry 985

Fall, 2o13 Exam # 2 **Take Home**

Distributed: Wed., 4 Dec. 13, 4:00PM Due: 5 Dec. 13, 10:00AM

This exam centers on the detector system in a very recent report of a new evaluation of the neutron lifetime that appeared in Physical Review Letters (PRL **111** (2013) 222501). You may need to obtain a copy the publication and use other information in the textbook in order to complete this exam. If necessary, you should be able to download the publication through the MSU library system.

Notes:

(1) that the authors state on page 2 that: "... the symbol ± ... [used] throughout the text corresponds to the standard (1σ) uncertainty."

(2) the authors talk about the solid angle and use the symbol Ω without dimensions in the text. However, its use in Eq. (3) clearly indicates that Ω is really the geometrical efficiency $\epsilon_{geo} = \Omega/4\pi$ in the usual notation.

1. (10 points) The manuscript indicates that there is an apparent discrepancy between two styles of measurement of the lifetime of the neutron in the literature at the level of 2.6σ. One reason to perform different kinds of measurements of a given quantity is the systematic errors will be different in the different measurements. At the conclusion of the work the authors indicated the discrepancy should be increased to 3.8σ and thus "It is important that this discrepancy be resolved ... [with more work]." What is the probability (give a number) that the two types of measurements are in fact discrepant after this work?

2. The authors indicated that they used two neutron detectors. A *neutron flux monitor detector* with ^{6}LiF as the active ingredient followed by an *Alpha-Gamma Detector* with $^{10}B_4C$ (ρ=2.52 g/cm^3). The latter detector was used to determine the absolute flux of neutrons. The neutrons were in a monoenergetic beam with a wavelength λ_{mono}=0.46905 nm. They indicated in Eq. (1) that the cross section for the reaction could be linearly scaled with wavelength with the expression:

$$\mathrm{r_{mono}} = \epsilon_0 \frac{\lambda_{\mathrm{mono}}}{\lambda_0} \mathrm{R_O}$$

where r_{mono} was the observed rate, ϵ_0 and R_0 were the detection efficiency and observed rate in the monitor for thermal neutrons, respectively. In the present work they report the solid angle was 4.2021x10^{-3} and further digging indicates that the target-to-detector distance was 7.50 cm.

(a) (5 points) What is the kinetic energy in eV of the monoenergetic neutrons in this experiment.

(b) (5 points) Explain the basis of the linear scaling of the reaction rate with neutron wavelength.

(c) (5 points) The authors indicated that the efficiency of the alpha-gamma detector was calculated from the activity of a well-known ^{239}Pu source but don't give any details. It turns out this calibration procedure gives the geometrical efficiency of the alpha particle detector. What activity in Ci of a ^{239}Pu source would be necessary to obtain enough counts to determine the efficiency of the alpha detector at least at the level of 0.1% reported in the paper in a 1000.0 second measurement?

(d) (5 points) The authors indicate that they used a "totally absorbing" $^{10}B_4C$ target in the alpha-gamma detector as part of their experiment. Explain why there is no such thing as "totally absorbing" target for neutrons.

(e) (5 points) What is the cross section for neutron absorption by the "totally absorbing" target at the neutron energy used in the experiment?

(f) (5 points) What thickness of the $^{10}B_4C$ target material would be necessary to absorb the neutron beam at the level of 0.9999 ?

(g) (10 points) Explain the basis of neutron detection by this alpha-gamma device. Be sure to mention what reaction takes place, what particles are detected and if any other absorbing materials could be used.

3. Further investigation of the alpha-gamma detector indicates that the two high-purity gamma-ray detectors were 18% intrinsic germanium detectors that are "deeply buried within cylindrical shields of lead, iron and copper." The shields are 36 inches in diameter.

(a) (5 points) The choice of these specific materials for the shielding of lead, iron and copper (in that order, outside to inside) is somewhat unusual for two reasons. Explain.

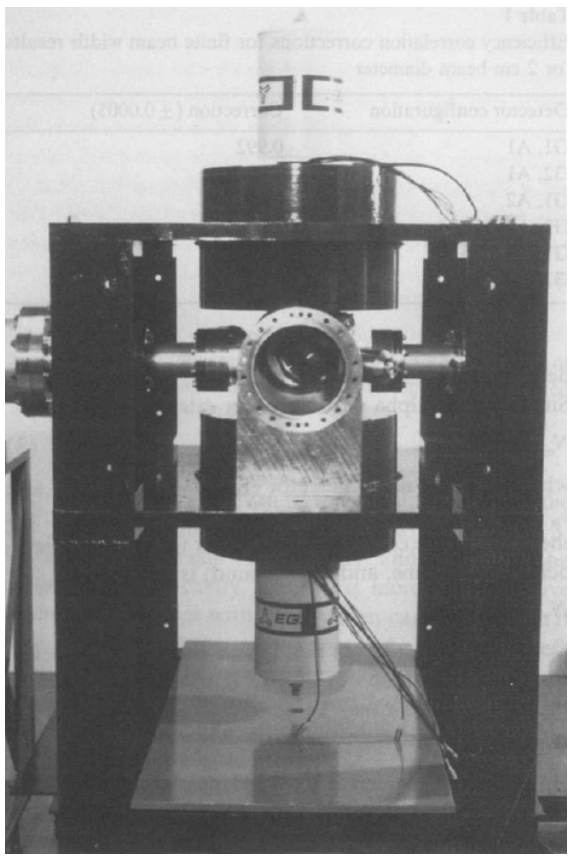
(b) (5 points) The designers of the alpha-gamma neutron detector state that the gamma-ray counting rate has to be corrected for "summing." Describe the origin(s) of the most important summing correction(s) when the neutron detector used with a $^{10}B_4C$ target.

4. The neutron beam and targets are contained in an evacuated beam line. Provide **concise** and accurate answers to the following three questions about vacuum equipment that might be part of this experiment.

(a) (5 points) Describe the purpose of the magnet in a standard cold-cathode vacuum gauge.

(b) (5 points) A photograph of the prototype system (below) seems to indicate that the central chamber could be pumped by a turbo molecular pump connected (CF-100 flange, left side) to the vacuum chamber with a straight pipe (CF-40 flanges) 1.00 m long with a internal diameter of 35 mm. What is the effective speed of this vacuum pump, S=250 L/s in molecular flow, at the chamber wall given this arrangement?

(c) (**Antibonus**: 0 points, -5 points if wrong) What is the most likely (highest pressure) gas and what is its source inside the central chamber immediately after the air is removed and the pumping system has just reached its base pressure?



5. The charged particles from the reaction were observed in "a passivated implanted planar silicon (PIPS) detector", see for example:
`http://www.canberra.com/products/detectors/pdf/passivated_pips_C39313a.pdf`

(a) (5 points) The term "passivated" means that the PIPS detector is a variation of a silicon surface barrier detector (SSD). Describe an important failure mode for SSD's that are operated for long continuous periods of time in vacuum.

(b) (5 points) What is the minimum circular area of the PIPS detector that could be used in this geometry if the incident charged particles were "detected with unit efficiency" as stated by the authors?

6. No information on the data collection system was included in the publication but some digging indicates that the counting rates were recorded in CAMAC scalers and readout over a GPIB crate interface (see figure below). The GPIB (IEEE-488 standard) bus can transfer 8 bit words (1 byte) at a maximum rate of 1 Mbyte/s. Individual spectra of four specific detectors could be collected in an MCA for diagnostic purposes. The observed counting rate in the detectors was reported (separately) to be 400/s and the deadtime was reported to be $\sim 2\mu$s. A DAQ cycle consists of clearing the scalers, enabling the counting in the scalers, (wait), disabling the scalers, and transmitting the scaler values to the computer.

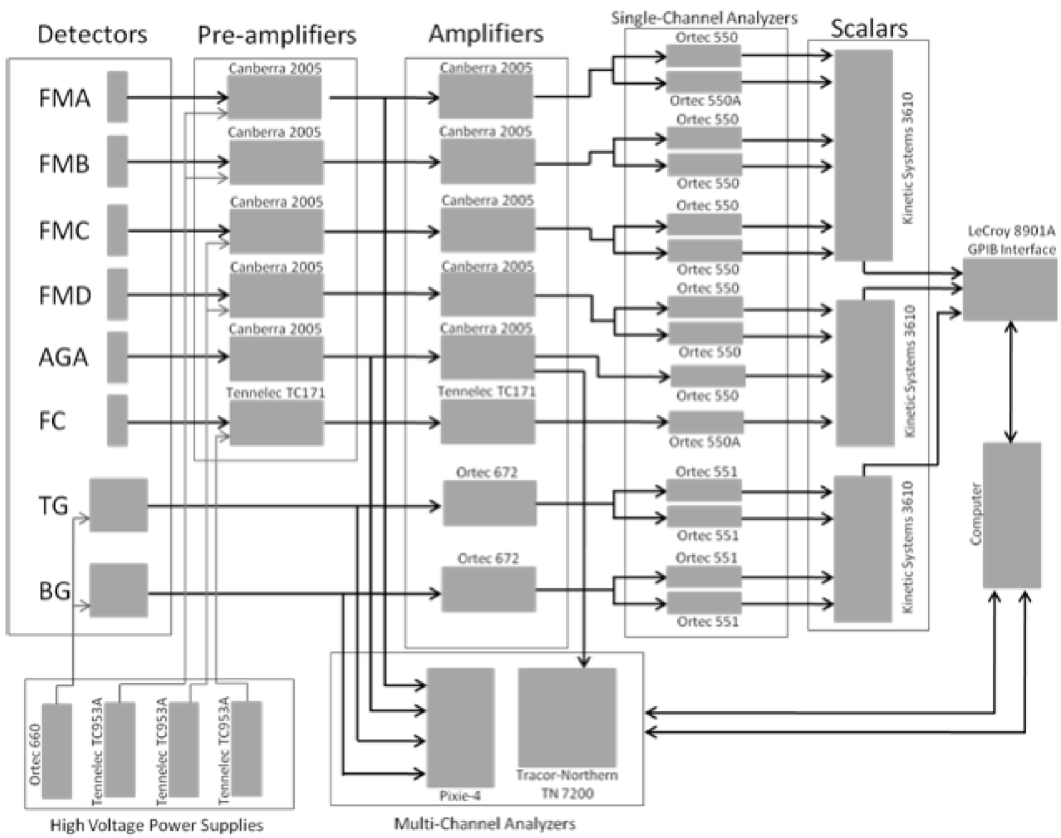
   (a) (5 points) The diagram shows that the CAMAC scaler is a Kinetic Systems model 3610 that can count signals up to 50 MHz. Describe the most-likely source of the reported deadtime of $\sim 2\mu$s in their electronics system.

   (b) (5 points) This system clearly falls into the category of "slow logic" but is it a "coincidence system" or not? Explain.

   (c) (5 points) What is minimum amount of time required to read out the fourteen scaler values over the CAMAC/GPIB interface?

   (d) (5 points) In the separate report, the authors indicated that the PIXIE-4 MCA system did not have sufficient resolution for the alpha-particle signal from the Alpha-Gamma detector and they added the Tracor-Northern TN-7200 MCA to also process this signal. The PIXIE-4 system is based on a 75MHz 14-bit flash ADC while the TN-7200 uses a 50MHz 12-bit Wilkinson ADC. Explain how the slower ADC with a lower number of bits might produce a higher resolution spectrum in this case.

   (e) (Bonus, 5 points) A glaring error is repeated several times in this electronics diagram, what is that error?



FMA – FMD are the four Flux Monitor detectors labeled A to D.
AGA – the alpha detector in the Alpha-Gamma device
FC – is an external beam line monitor detector
TG – BG are the Top and Bottom Gamma-ray detectors in the Alpha-Gamma device