Chemistry 985

Fall, 2o19 Exam # 2
Distributed: Tue., 3 Dec. 19 Due: Thurs., 5 Dec. 19, 10:30AM

1. (20 pts total) Provide concise and accurate answers to the following questions about vacuum components.

   (a) (4 pts) What important feature(s) contribute to the fact that the speed of mechanical vacuum pump (oil-filled or dry pump) is essentially constant over its working range?

   (b) (4 pts) Describe any variation of the pumping speed of a turbomolecular pump as a function of radius of the pump inlet?

   (c) (4 pts) What is the ratio of the conductances of two straight pipes, each 1 m long, that have diameters of 7.5 cm and 5.0 cm for gas in laminar flow?

   (d) (4 pts) What molecule (or atom) is most likely to be the largest constituent of the residual gas inside a metal chamber that has just been pumped down to $1\text{x}10^{-7}$ mbar and what is its source?

   (e) (4 pts) What is the fundamental (only?) difference between a nude ion gauge and a standard Bayard-Alpert ion gauge?

2. (10 pts total) Provide concise and accurate answers to the following questions about photomultipliers.

   (a) (3 pts) Describe the difference between an AC and a DC coupled anode signal.

   (b) (3 pts) Describe why an ACTIVE base is better for high counting rates than a PASSIVE base.

   (c) (4 pts) The Hammatsu R1306 photomultiplier is used extensively for high resolution measurements in nuclear science. What is the value of δ for this tube when run at the typical gain? The Spec Sheet

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The following questions are based on information that can be found in the published description of two detector systems on the MESSENGER space craft that was sent to determine the elemental distribution of the surface of Mercury. The paper by Goldsten et al. [Space Sci Rev (2007) 131: 339–391, DOI 10.1007/s11214-007-9262-7] is a very thorough and informative summary of the mission, the measurement techniques, and of an instrument package containing a gamma-ray and a neutron spectrometer. It is interesting to see that the manuscript was under review for more than one year before it was accepted.

3. (10 pts total) The salient parameters of the gamma-ray spectrometer are given in Table 2 of the manuscript. On page 359 the authors comment that that the crystal is a "coax HPGE" make of n-type material and is fully depleted at 2,400 V, giving a capacitance of 25 pF but is operated at higher voltage to ensure complete charge collection. The charge collection time is said to be 100 ns, and the signal is shaped with a 6 μs shaping time. Note that Figure 7 indicates that the output of the preamp is not a step function but rapidly decays.

   (a) (2 pts) What is the advantage of using "n-type" germanium for space-based gamma-ray spectrometers?

   (b) (2 pts) What charge carriers are collected on the central contact of this detector?

   (c) (6 pts) Using the expression in Equation 12.11 in the textbook, make an estimate of the radius of the inner (central) contact of this detector [read the description of the equation carefully].

4. (10 pts total) The authors indicate that the ADC is a 14 bit successive approximation device with a dithering circuit to smooth out the DNL. On page 360 that the dithering is reported to correspond to 5% of full scale. It is also reported in several places that the total time to process an event is approximately 100 μs.

   (a) (2 pts) What is the more common name for a "dithering" circuit used to smooth out the DNL in an ADC?

   (b) (2 pts) What is the (interger) number of bits in the dithering circuit?

   (c) (2 pts) Make an estimate of V_{LSB} for this ADC system given the energy range in Table 2.

   (d) (2 pts) The expected data rate is (only) 5k/s, what is the advantage of using bipolar signals in this device?

   (e) (2 pts) What is the true event rate at the maximum recorded event rate of 5000/s (see Table 2).

5. (10 pts) The authors indicate on page 359 that a special circuit is needed to reset the preamp after a large signal from a cosmic ray is generated in the germanium. Estimate the amount of energy deposited in the germanium by a cosmic ray that traverses the detector parallel to the coaxial contact. What is the amount of charge delivered to the preamp by this event?

6. (10 pts) Table 4 in the paper presents the measured resolution of the gamma-ray spectrometer as a function of energy obtained with radioactive sources. It also contains the results of a measurement with a pulser and background. Assuming that the pulser data represents the electronic noise, W_E^2 in the text, and that there is no contribution from incomplete charge carrier collection, make a graph of W_D as a function of E_γ for the source data (omit the background point) similar to Figure 12.9 in the text. The result shows that the data approximately follows the expected $\sqrt{E}$ dependence.

7. (20 pts total) The neutron spectrometer relies on neutron capture in a special plastic scintillator, BC-454 5% loading, see attached spec-sheet. The block of plastic is covered on two sides by a Lithium-glass scintillator plate and on the other faces by 0.25 mm thick gadolinium metal, see page 354. The detector is triggered by observing a double coincidence between one Li-glass detector and a delayed signal in the BC-454 plastic and not a triple coincidence when both Li-glass detectors plus the plastic fire. The triple coincidences are ascribed to cosmic rays that pass through the three components and are used as a reference.

   (a) (5 pts) Compare the stated rate of approximately 40/s cosmic ray events that travel perpendicular to the the detector axis (see page 365) to the average rate at the surface of the earth.

   (b) (5 pts) The neutron detector was tested with a ^{252}Cf source having a neutron counting rate of 6.504x10^7 n/s (at that time) at the Los Alamos National Laboratory. What is the decay rate of this source in Bq?

   (c) (5 pts) Estimate the maximum light output from the BC-454 scintillator based on the energetics of the neutron capture event.

   (d) (5 pts) The authors show that the neutron capture event in the detector only gives the equivalent to the signal from a 94 keV electron. Give a plausible reason for the large discrepancy between this number and your previous answer.

– that's probably enough –

BC-454 Natural Boron-loaded Premium Plastic Scintillator

BC-454 is a boron-loaded, plastic scintillator formulated to provide efficient detection of fast and slow neutrons. The standard material contains natural boron (19.9% ^{10}B) at a concentration of 5% by weight. Low energy neutrons are detected through the ^{10}B (n, d) capture reactions, and high energy neutrons are detected via elastic scattering of protons.

The principal application of this material is total-absorption neutron spectrometry. A fast neutron will produce a prompt recoil proton pulse. Neutrons that are sufficiently thermalized within the scintillator are likely to undergo the ^{10}B (n, d) capture. A capture pulse, in delayed coincidence with the prompt pulse, is used to identify neutron events. For neutron energies below 200keV, the capture time constant is dependent only on the ^{10}B concentration. For a 5% boron loading, the capture time constant is approximately 2.7μs.

BC-454 is available as sheets, rods, thin films and fibers. Other boron concentrations up to 10% are available on request.

	% Boron Loading		
Scintillation Properties	1%	5%	10%
Light Output, %Anthracene	60	48	38
Decay Time (ns)	2.2	2.2	2.2
Wavelength of Max. Emission, nm	425	425	425
Bulk Light Attenuation Length, cm	120	120	120
Atomic Composition			
No. of C Atoms per cm^3 ($x10^{22}$)	4.63	4.43	4.18
No. of H Atoms per cm^3 ($x10^{22}$)	5.18	5.18	5.18
No. of ^{10}B Atoms per cm^3 ($x10^{20}$)	1.12	5.59	11.25
No. of Electrons per cm^3 ($x10^{23}$)	3.34	3.33	3.32

General Technical Data –

Base	Polyvinyltoluene
Density [g/cc]	1.026
Expansion Coefficient (per°C,<65°C)	~7.8X10^{-5}
Refractive index	1.58
Softening Point	60°C
Vapor Pressure	May be used in vacuum
Solubility	Soluble in aromatic solvents, chlorinated solvents, acetone, etc. Unaffected by water, dilute acids, lower alcohols, alkalis and pure silicone fluids or grease.