NE-104A

Final Exam, Part 1, Spring 2005

Saturday, May 14 ● 8:00 to 11:00 a.m. ● 3106 Etcheverry Hall

(Closed book. See bottom of page 4 for constants, formulae, and data.)

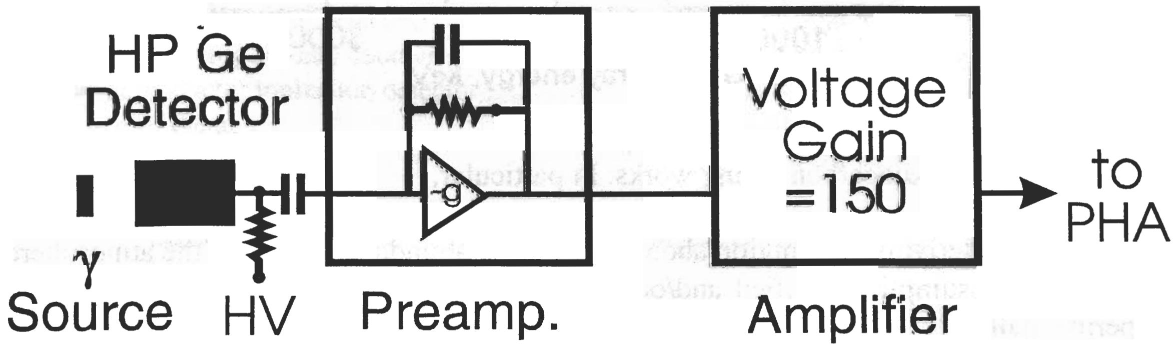
1. A scintillation counter registers 1580 counts in 10 seconds when measuring a radioactive source plus background, 40 counts in 2 second when the source is removed (background only). Assume that the uncertainties in the counting times are negligible and that the counter dead time is zero.

   a. What is the net counting *rate*, due to the source alone, in counts per second *with uncertainty*? (3 points)

   b. If the source strength is (1.00±0.04) μCi (microcuries), what is efficiency of the counter *with uncertainty*? (3 points)

   c. How long would one have to count to reduce the relative uncertainty in the total counting rate (source plus background) to ±1%? (3 points)

2. Refer to the diagram below in answering questions 2.a,b,c. The High Purity Ge Detector is used to measure 1099 keV γ ray from a ^{59}Fe source. The preamplifier has a gain of 1 volt per picocoulomb.

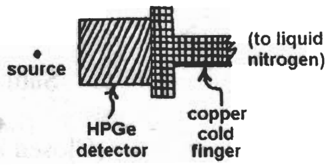


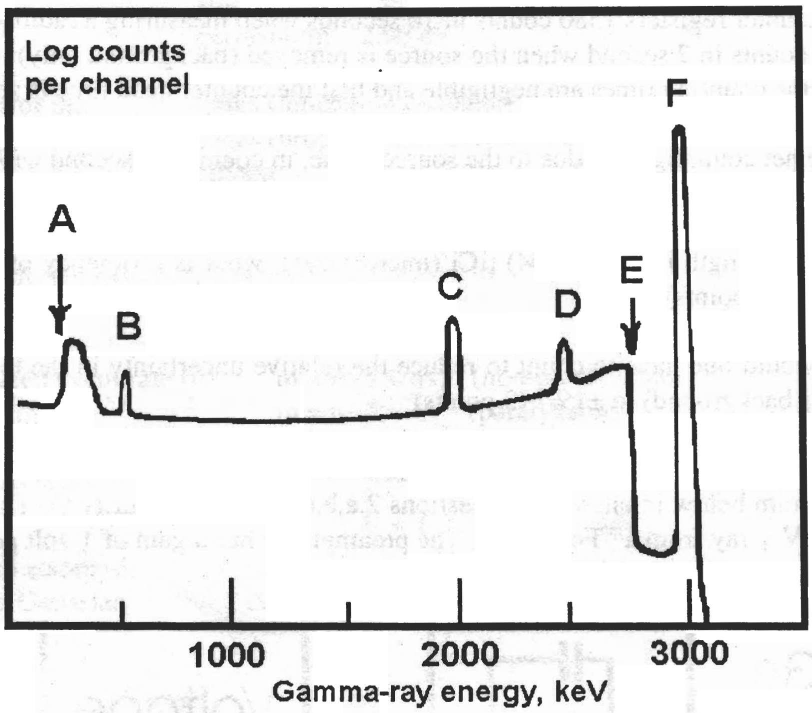
   a. What is height of the output signal corresponding to the full-energy peak, in volts? (3 points)

   b. What is the energy resolution of the full-energy peak (FWHM, in keV) due to the statistics of charge collection only? (3 points)

   c. The energy resolution due only to electronic noise, measured with the use of a precision pulser, is 0.85 keV FWHM. What is the energy resolution of the system (FWHM, in keV), due to *both* electronic noise and the statistics of charge collection? (3 points)

3. The spectrum shown below represents a single, monoenergetic gamma ray (E_γ = 2975 keV) recorded with a HPGe spectrometer system. Features of the spectrum are marked by letters A-F. (1) *Name* each feature, (2) give the *exact energy* at which it occurs, and (3) describe briefly the *physical process(es)* that give rise to it. (Note that two features of the spectrum are caused or enhanced by the presence of a massive "cold finger" behind the detector.) (12 points)





4. Describe briefly how radiocarbon dating works. In particular,

   a. What is the underlying assumption about the isotopic abundance of ^{14}C in the atmosphere?
   b. How is this assumption verified and/or corrections for deviations from the assumption made experimentally?
   c. What event "starts" the clock?

(6 points)

5. Multiple choice: Choose the ***best*** answer (1 point for each correct, -1/3 point for each wrong answer):

   a. A standard pulse preamplifier-amplifier combination is charge-sensitive:

      1) ___ except with pulses longer than the amplifier shaping time constants
      2) ___ except with small amplitude pulses
      3) ___ except at low count rates
      4) ___ under all circumstances

   b. The signal in a proportional counter or geiger counter is generated:

      1) ___ mainly by drift of electrons
      2) ___ mainly by drift of positive ions
      3) ___ mainly by drift of electrons or positive ions, depending on whether the event occurs near the cathode or the anode
      4) ___ when the charges reach the electrodes

c. Germanium is a better material than silicon for gamma-ray detectors mainly because of its

1) ___ higher atomic number
2) ___ smaller band gap
3) ___ lower average ionization energy
4) ___ lower fano factor

d. If a source is counted for a length of time T, the uncertainty in the counting rate σ_R is proportional to:

1) ___ T
2) ___ $T^{1/2}$
3) ___ $1/T$
4) ___ $1/T^{1/2}$

e. The following are necessary for Gaussian statistics to apply:

1) ___ >> 1 atom
2) ___ counting interval << $t_{1/2}$
3) ___ >> 1 observed decay
4) ___ all of the above

f. The sign of the bias voltage can be reversed without loss of function in a:

1) ___ gas-filled ionization detector
2) ___ gas-filled proportional counter
3) ___ semiconductor ionization detector
4) ___ none of the above

g. Neutron activation analysis is a method to identify and assay:

1) ___ naturally occurring radioactive isotopes
2) ___ chemical compounds
3) ___ elements
4) ___ fundamental particles

h. A detector with high intrinsic efficiency

1) ___ detects a large fraction of all radiations emitted by the source
2) ___ detects a large fraction of all radiations emitted in the direction of the detector
3) ___ has a low noise-to-volume ratio
4) ___ uses little power per unit volume

i. A proportional counter can have better energy resolution than a silicon semiconductor detector:

1) ___ for heavy particles
2) ___ at sufficiently high energies
3) ___ at sufficiently low energies
4) ___ in no case

j. The observed counting rate m of a non-paralyzable counter with dead time τ:

1) ___ determines the event rate n unambiguously
2) ___ approaches $1/\tau$ for large n
3) ___ is a higher than in a paralyzable counter with the same τ and n
4) ___ all of the above

CONSTANTS, FORMULAE, AND DATA:

electronic charge	e/c	$= 1.602 \times 10^{-19}$ Coulomb
rest mass of electron	$m_e c^2$	= 511 keV
curie (Ci)	3.7×10^{10} becquerels (disintegrations per second)	

Average energy to create an ion pair in:	gases	30 eV
	silicon	3.62 eV
	germanium	2.96 eV

Effective Fano factor in:	gases (ionization chamber)	0.2
	gases (proportional counter)	0.5[a]
	silicon	0.09
	germanium	0.06

[a] includes the effect of charge multiplication

Relationship between event rate (n) and counting rate (m)

$m = n/(1 + n\tau)$ (non-paralyzable)

$m = n e^{-n\tau}$ (paralyzable)

Energy of Compton scattered photon

$$E_\gamma' = \frac{E_\gamma}{1 + \left(\frac{E_\gamma}{m_e c^2}\right)[1 - \cos(\theta)]}$$

Ratio of FWHM to standard deviation (σ) for a Gaussian: 2.355

Nuclear Engineering 104A
Spring Semester 2005
Final Examination
Neutronics Section

1. A ^{3}He counter is used to detect thermal neutrons. The neutrons are thermal neutrons and the detector is a cylinder of 1 cm diameter. Note that the thermal neutron capture cross section is 5300 barns.

   a What is the gas pressure (at 300°K in the tube if 63 percent of the neutrons which enter radially at right angles to the z-axis of the tube are captured in the helium gas ? (Hint: $0.63 = 1 - 1/e$)

   b. For a neutron which enters the tube perpendicular to the z-axis but at a forty-five degree angle to the radial vector, find the probability of capture.

   c. For a neutron which enters the tube in the plane containing the radial vector and the z-axis, with a forty-five degree angle to the z-axis, find the probability of capture.

2. Sketch the probability of capture of a neutron vs. energy in a Bonner sphere (i. e. a "REM-ball") and discuss why this curve is relevant to neutron dosimetry.

3. A thermal neutron enters human tissue. The primary component of tissue is water. Describe the primary nuclear reaction which occurs in the tissue.

4. A one gram sample of ^{27}Al is exposed to fast neutrons. The exposure time is 30 minutes. After a one-hour cooling-off period, the sample is placed on a germanium detector. The detector sees 35,000 counts in the ^{24}Na line at 2.7 MeV after counting for ten minutes. The detector's efficiency at this gamma energy is 1.5×10^{-4}. The average cross section for $^{27}\mathrm{Al}(n,\alpha)^{24}\mathrm{Na}$ is 300 mb and the half-life of ^{24}Na is 15 hours.

   a. Estimate the flux which the sample was exposed to, ignoring the effects of decay during the irradiation, the cooling off period, and the counting period.

   b. Find a first-order accurate correction to your result above by assuming that all the counts came in at the middle of the counting time and that all of the activation was created midway through the exposure time.

5. Suppose that a small amount of Xe gas is mixed into a ^{3}He ionization tube used to measure thermal neutrons. How will this change the "wall effect": (a) increase the ratio of full energy counts to partial energy counts, (b) leave this ratio unchanged, (c) decrease this ratio?

6. Suppose that the natural uranium slugs in the subcritical assembly were replaced with enriched uranium, so that the neutron multiplication factor k_{eff} was increased from 0.85 to about 0.99. If the assembly were driven by a neutron source located at one

side, sketch the neutron flux distribution across the core, and compare with the flux distribution with the natural uranium fuel.

7. A small portion of the fusion reactions between deuterium and tritium release a 16.8 MeV gamma ray. This gamma ray can be converted into a Compton electron with virtually the same energy. It is desired to design a detector which senses all Compton electrons with energies above 15 MeV. Using special relativity, a 15 MeV electron has a speed of 0.999457 c. It is desired to use the Çerenkov effect to detect this fast electron. If we want the Çerenkov radiation threshold to correspond to the 15 MeV electron, and carbon dioxide gas has an index of refraction given by $n = 1 + 3.6 \times 10^{-6} p$, where p is the absolute pressure in psi, what CO_2 gas pressure should we use in the Çerenkov cell?

8. A BF_3 tube is used to detect 1 MeV neutrons. List in rank order (lowest to highest) the expected count rate: (a) the bare tube, (b) the tube placed inside a 15 cm diameter paraffin cylinder, and (c) the tube placed inside a 150 cm paraffin cylinder. Explain your ordering.

9. A cargo shipment is suspected of having a 1 kilogram plutonium piece concealed in 200 kilograms of bananas. A neutron generator is used to inspect the cargo. The neutrons are produced in a 10 μs pulse. Neutron detectors are set up to detect thermal neutrons following the pulse.

   a. Sketch the expected neutron signal vs. time with and without the plutonium piece in the cargo.

   b. Explain the underlying physical process which might lead to detection of the plutonium.

   c. What naturally occuring element would be present in the bananas which might cause a high level of gamma ray activity in the cargo, with or without the plutonium present?