

Chemical Physics Cumulative Examination

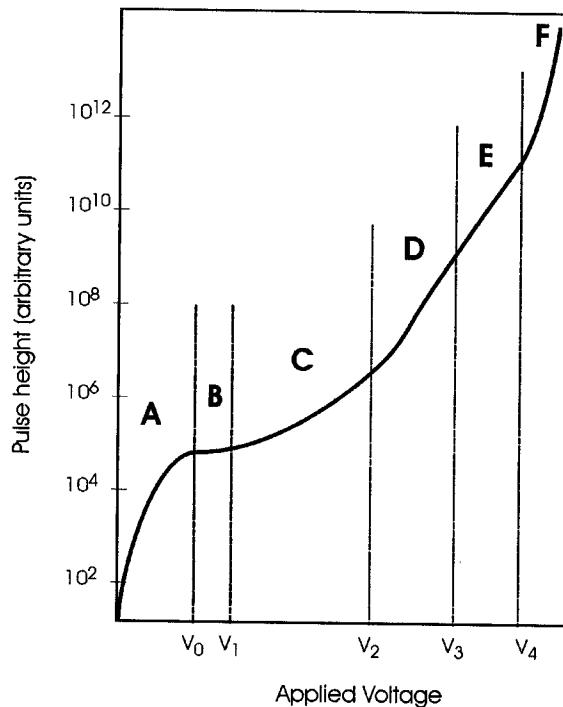
March 17, 2003

The following 7 questions cover topics and techniques in radiation detection and measurement. It is necessary to show all work to receive full credit for each question.

Expected point distribution: 100-80% 3 points; 79-65% 2 points; 50-64% 1 points. 65% or higher is required to receive a chemical physics PASS grade.

Question 1 (14 points)

(a) An ion counter consisting of an anode axial wire and a cylindrical cathode, when filled with a suitable gas and connected to a high gain amplifier, produces pulse heights as a function of applied voltage for an alpha particle as shown below. Identify and briefly describe the operational characteristics of regions A – F.



(b) A certain proportional counter has a 2 cm radius with a center wire diameter of 4.0×10^{-3} cm. The counter is filled with 1 bar methane and operated at 4000 V. Under what conditions of pressure and voltage would the same gas multiplication be obtained in a methane-filled counter of 1 cm radius and 4.0×10^{-3} cm wire diameter, given that the multiplication factor goes as

$$M = f \left[\frac{V}{\ln(b/a)}, Pa \right]$$

where a is the wire radius and b is the chamber radius.

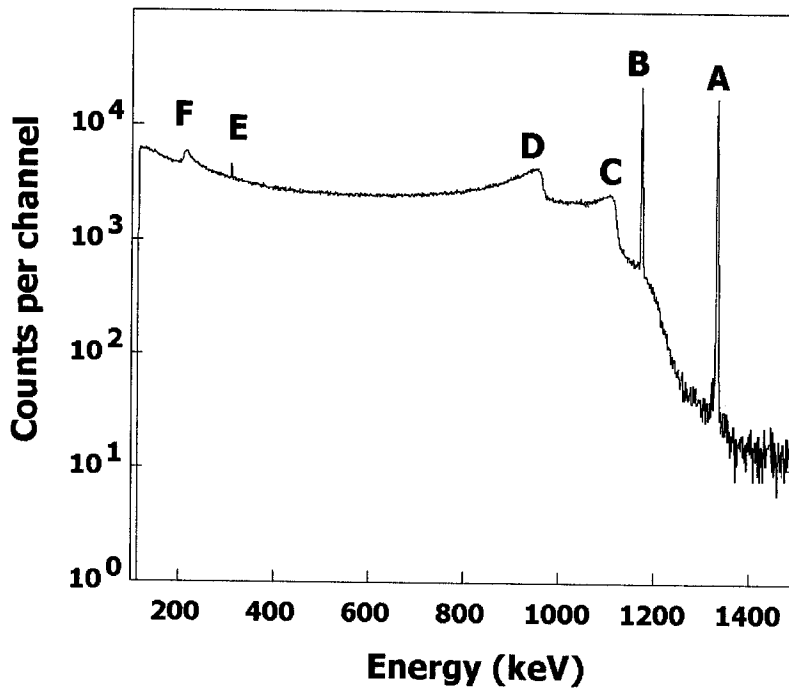
Question 2 (14 points)

(a) Two models of the dead time behavior of counting systems are paralyzable and non-paralyzable response. Describe, either in words or by illustration, the characteristics of each of these responses.

(b) The experimental determination of dead times can be accomplished using the two-source method or the decaying source method. Describe in detail one of these methods, making sure to state the requirements, the results, and any precautions or limitations to the technique.

Question 3 (10 points)

The ^{60}Co spectrum shown below was obtained with an HpGe detector operated with no Compton suppression. Identify each of the features A through F labeled on the spectrum below. The decay sequence following the beta decay of ^{60}Co is given in Question 4.

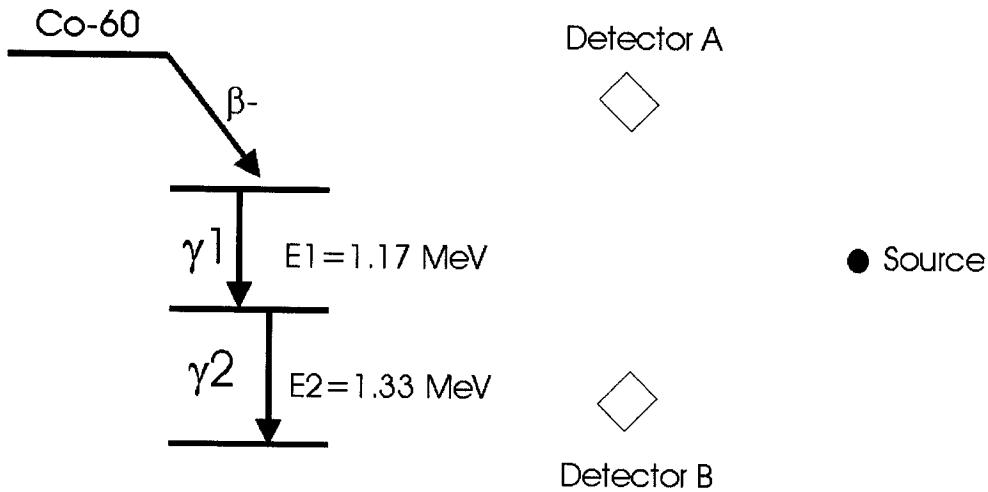


Question 4 (15 points)

The disintegration rate of a ^{60}Co source is to be determined using gamma-gamma coincidence techniques. The decay sequence for ^{60}Co is given below. Two HpGe detectors (A and B) of identical type are placed around the source position. Show that the relation

$$\frac{R_A R_B}{R_{AB}} = \left(1 + \frac{\epsilon_{2A}}{\epsilon_{1A}} \right) R_0$$

can be used to determine the disintegration rate R_0 , where R_A is the counting rate in detector A, R_B is the counting rate in detector B, R_{AB} is the coincident rate, and ϵ_{1A} and ϵ_{1B} are the efficiencies for detecting γ_1 and γ_2 , respectively, in detector A.



Question 5 (20 points)

(a) A ^{44}S nucleus traveling at $1/3$ the speed of light ($c = 3 \times 10^8 \text{ m/s}$) is Coulomb excited in a Au target and emits a 908-keV gamma ray that is detected at 42° relative to the direction of motion by a $3'' \times 3''$ NaI detector located 40 cm from the Au target. What is the energy of the detected photon? You can assume that emission is from a point source and that the detector is a point detector.

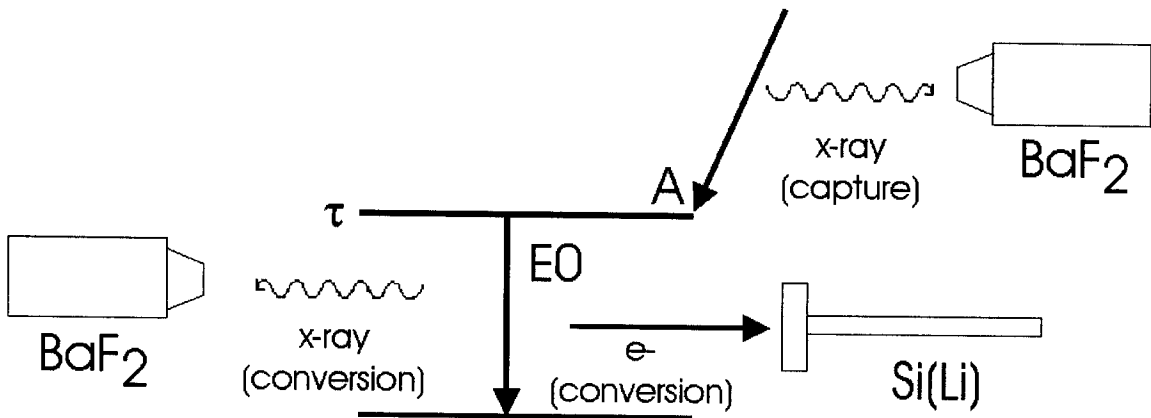
(b) Determine the energy of the center-of-mass system in a collision between a 15 MeV proton and a 45 MeV ^{16}O ion when the particles are moving in opposite directions.

Question 6 (15 points)

The lifetime of an excited state A is to be determined by the fast coincidence method using two BaF₂ crystals attached to fast photomultiplier tubes. The detectors will detect x-rays associated with both the electron capture and internal conversion processes shown in the diagram below. Since these x-rays are identical, there is an ambiguity between the x-ray signals, which start and stop the fast timing circuit. Show that for such a system, the lifetime τ of state A can be determined from the coincidence timing spectrum using the relation

$$\sigma_{\text{delayed}}^2 = \sigma_{\text{prompt}}^2 + 2\tau^2$$

where σ_{prompt} is the full-width at half-maximum (FWHM) of the prompt coincidence timing curve and σ_{delayed} is the FWHM of the delayed timing spectrum.



Question 7 (12 points)

A certain 12-stage photomultiplier tube has a single dynode multiplication factor $\delta=5$.

- What is the gain of the photomultiplier tube?
- For a single photoelectron event at the first dynode, what is the percent relative variance in the number of secondary electrons produced?
- What is the transit time for a single photoelectron event given an interdynode spacing of 12 mm and a potential difference of 150 V per stage?
- If a scintillation event releases 100 photoelectrons from the photocathode, what average dc current is produced for a pulse rate of 10^5 per second for the photomultiplier tube gain determined in (a)?