Operation and Characteristics of Gas-Filled Ionization Detectors

Objectives: This experiment will familiarize you with gas-flow proportional counters and Geiger-Müller (G-M) counters, and with some of the techniques for using these instruments to detect and measure α, β^- and γ radiation.

References: Ehmann & Vance: pp. 205-220.

PROCEDURE

A. Determination of the β^- Plateau and the Resolving Time of a G-M Counter

NOTE: The basic operation of the counter/scaler systems will be demonstrated by the instructor. You should always ensure that the high voltage (HV) adjust is set to zero before *turning your scaler unit on.*

To determine the plateau of the G-M counter, place a ^{36}Cl source (a β^- emitter) on the third shelf of the sample holder. With the scaler in the count mode, slowly increase the HV until you just start to register counts on the scaler. Take a 60-second count at this voltage and repeat the measurement at 30-volt step increases in the applied HV. Plot your data (cpm vs. HV) as you make successive measurements to ensure that you don't proceed more than about 40 volts beyond the plateau region or you will damage the counter. On your graph, note the voltage at the start and end of the plateau region and select a voltage about 1/3 of the way along the plateau as your counter operating voltage. Calculate the slope of the plateau as % increase in counting rate per 100 volt increase in applied voltage.

The resolving time of the detector will be determined by the method of paired sources. Place one half of the split ^{90}Sr source (S1) and the blank (B2) on the lowest shelf of the holder. Count for exactly 5 minutes and record the total counts. Carefully remove the blank and replace it with another split source half (S2). Again count for 5 minutes and record the total. Carefully remove the original split source half (S1) and replace it with a second blank half (B1) and count for 5 minutes. Remove the second source (S2) and replace it with the original blank (B2), then count the two blanks for 5 minutes and record.

Calculate the observed count rate (cpm) for each measurement. The true count rate (R) is related to the observed count rate (r) by

$$R = \frac{r}{1 - r\tau} \qquad \text{(I.1)}$$

where τ is the resolving time of the instrument. Your results should show that

$$(r_{S1,B2} + r_{B1,S2}) > (r_{S1,S2} + r_{B1,B2}) \quad (I.2)$$

because of coincidence losses. If the count rate is corrected for coincidence losses (via eq. I.1), then

$$R_{S1,B2} + R_{B1,S2} = R_{S1,S2} + R_{B1,B2} \quad (I.3)$$

From equations I.1 and I.3 it follows that

$$\frac{r_{S1,B2}}{1-r_{S1,B2}\tau} + \frac{r_{B1,S2}}{1-r_{B1,S2}\tau} = \frac{r_{S1,S2}}{1-r_{S1,S2}\tau} + \frac{r_{B1,B2}}{1-r_{B1,B2}\tau} \quad (I.4)$$

If the blank is considered negligible, and terms in τ^2 are neglected, then eq. I.4 can be rearranged to give

$$\tau = \frac{r_{S1,B2} + r_{B1,S2} - r_{S1,S2}}{2\, r_{S1,B2}\, r_{B1,S2}} \quad (I.5)$$

Calculate the resolving time (in µsec) according to eq. I.5, and check the relationship in eq. I.3. Using eq. I.1 and your measured resolving time, determine the count rate above which coincidence losses exceed 5% for your G-M counting system.

B. Determination of the α and β^- Plateaus and Resolving Time of a Proportional Counter

Repeat the above measurements for the gas-flow proportional counter. For the plateau measurements use a ^{238}U source and 40-volt step increases. You should observe two plateaus, first the α plateau, then the β^- plateau at higher voltage. Be careful not to increase the applied voltage to more than 50 volts above the β^- plateau region or damage to the counter could occur. Note the voltage range for each plateau, and calculate the slope of each as above.

Measure the resolving time of the proportional counter at the operating voltage for the β^- plateau using the split ^{90}Sr sources. Using eq. I.1 and your measured resolving time, determine the count rate above which coincidence losses exceed 5% for the proportional counter counting system. Compare your results with those for the G-M counter.

C. Output Pulse Characteristics

With an oscilloscope (Your instructor will show you how to connect the oscilloscope and how to use it.), monitor the output pulses of your G-M counter and a proportional counter. You will need to place a strong source by the counter while you do this. Measure the pulse size and estimate the dead time and recovery time of the counters. Sketch the pulse shapes. Look for any changes associated with the use of different radioactive sources (e.g., changes as a function of β^- energy or α vs. β^- radiation for proportional counter).

D. Statistics of Radioactive Decay

Place a β^- source on an appropriate shelf of your G-M counting system so that the count rate is about 500 cpm. Make thirty 30-second measurements of this activity. Be careful to ensure that you use the exact same counting time for each measurement. Note the highest observed count value and the lowest. Divide the range of values into 4 or 5 equal intervals (bins) and assign each value (x_i) to the appropriate bin. Make a bar graph of the number of values found in each of the bin as a function of the interval. Calculate the mean ($\overline{x}$) and the standard deviation, s, where n is the total number of determinations.

$$s = \left[\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \overline{x})^2\right]^{1/2} \qquad \text{(I.6)}$$

Truly random processes, like radioactive decay, are described by the expression

$$P(x) = \frac{(\overline{x})^x e^{-\overline{x}}}{x!} \qquad \text{(I.7)}$$

where $\overline{x}$ is the observed average, and x the number of counts per 30 seconds. For a Poisson distribution, the standard deviation is equal to $(\mu)^{½}$, where μ is the true mean. Compare the standard deviation calculated in eq. I.6 with $(\overline{x})^{½}$.

Note the percentage of the time that the deviation $|x_i - \overline{x}|$ is greater than s, and greater than the probable error (= 0.6745s). This should occur for approximately a third (31.7%) and 50% of the observations, respectively.