Radioactivity

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Department of Physics

Equipment

Geiger-Muller tube and mount
Spectech ST-350 radiation counter (and software for data collection)
Radioactive sources: (^{137}Cs, ^{60}Co, ^{90}Sr, etc.)
Absorber set: sheets of Pb, Al, etc.

The purpose of this experiment is to introduce the student to some aspects of nuclear decay, including the statistics of this random process, the nature of the emitted radioactivity, and the units of and recommended limits to radiation exposure. The primary focus will be on the β decay of ^{137}Cs. Note that a β particle is an electron.

Theoretical analysis

Review the theory of statistics and its application to nuclear counting, i.e., to the interpretation of measurements of nuclear decay. Be sure that you are familiar with the definitions of: the mean, the standard deviation, the Poisson distribution, and the Gaussian (or normal) distribution. In your report, define the mean and the standard deviation of a set of nuclear decay data.

• Poisson distribution $P_P(n)$ - the probability for a random nuclear decay process of detecting n counts in a time interval t (r = average decay rate of sample, with rt = average number of counts in time interval t):

$$P_P(n) = \frac{(rt)^n e^{-rt}}{n!}.$$

• Gaussian distribution $P_G(n)$ - physical processes that contain an element of randomness, e.g., nuclear decays, obey this distribution function:

$$P_G(n) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left(-\frac{(n-rt)^2}{2\sigma^2}\right)$$

Here σ is the standard deviation of the distribution.

Include in your report the definitions of the radiation units currently in use for source activity (becquerel and curie), absorbed dose (gray and rad), and effective dose (sievert and rem). The becquerel, gray, and sievert are the accepted SI units for these quantities.

Collection and analysis of experimental data

Refer to the ST-350 radiation counter instruction manual for information on the operation of the Geiger-Muller tube and its associated electronics. (Use the Lablink software, the counter on "remote", and COM 2.) Notes: (1) For all your measurements, remember that the longer you count, the better the statistics and accuracy of your results! (2) Always use the side of the source that gives the higher count rate.

(1) Measure the Geiger-Muller (G-M) tube voltage characteristic and determine an appropriate operating voltage.

(2) Determine the G-M tube dead time or resolving time T using the split-source method described in the manual. A special set of sources is available. Estimate the experimental uncertainty in your result for T.

(3) Design a counting experiment to collect a data set for $rt \approx 10$. Use 500 counting intervals of 1 second each. Be sure that your results are not seriously affected by the dead time of the G-M tube.

(4) Fit your data set with a Gaussian distribution using Microsoft Excel or other suitable software. Extra credit: use suitable software to also fit your data to a Poisson distribution. Give the mean, standard deviation, and correlation coefficient for each fit.

(5) Devise two simple experiments, the first to determine the dependence of measured radiation intensity on the distance between source and detector and the second to determine the effect of the thickness of an absorber placed between source and detector. Note: place the absorbers as close as possible to the detector. This will minimize the radiation that is scattered into the detector that would have missed it otherwise. Note: you should also determine the background counting rate both before and after your measurements and use it to correct the measurements if it is an important factor.

Plot the number of measured counts N versus distance d on a log-log plot (log N vs log d). If d is large (compared to the dimensions of the detector), the number of counts should decrease as an inverse power of the distance d from source to detector, i.e.,

$$N(\text{counts}) \propto \frac{1}{d^n}$$

where n is an integer. Fit a straight line to your data and determine the value of n from the slope of this straight line. If a good fit is not obtained, explain why.

Plot the number of measured counts N versus absorber thickness t on a semi-logarithmic plot. Be sure to use all the available Al absorbers and to include zero thickness! Again, fit a straight line to your data. Does this plot confirm that, for a particular type of radiation, the number of counts decreases exponentially with increasing absorber thickness t according to

$$N(\text{counts}) \propto e^{-kt}$$

where k is a constant depending on the absorber material?

<u>Questions</u>

1. Explain how the three basic principles of time, distance, and shielding can be used to limit your exposure to radiation.
2. What was the effect of the dead time T of the G-M tube on your measurement with the highest counting rate? What fraction of the counts was lost due to the dead time?
3. Describe the sequence of nuclear transitions as ^{137}Cs decays to ^{137}Ba, taking into account that both β particles and γ rays are typically observed as decay products.
4. For the 5 μCi (microcurie) ^{137}Cs β source, calculate the exposure (i.e., absorbed dose) you would receive if you held this source in your hand for five minutes. Assume that all the radiation is absorbed by your hand (mass $\approx$ 1 kg) and that the total energy per decay is $\approx$ 1 MeV. Compare this exposure with the naturally-occurring background radiation received in one year ($\approx$ 1 millisievert = 1 mSv = 100 millirem) and with the typical exposure received from a medical x-ray ($\approx$ 0.1 mSv). The recommended yearly allowance for the additional radiation exposure for the general population from all other sources is 1 mSv.

<u>References</u>

Bleuler E. and G.J. Goldsmith, *Experimental Nucleonics*, HRW.

Melissinos,A.C., *Experiments in Modern Physics*, Academic Press (see Chapters 5 on radiation and 10 on statistics; also pages 52-56).

Taylor, J.R. and C.D. Zafiratos, *Modern Physics for Scientists and Engineers*, Prentice Hall (Sect. 13.12 has definitions of activity, etc.).

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