Radiation Lab 12

Equipment SWS, PASCO Geiger tube, β and γ sources

Reading John R. Taylor, "An Introduction To Error Analysis," 2nd ed. (University Science Books, 1997)

Comment In this write-up, counting times and source positions are often given. These are *suggestions*. You should choose somewhat different times and source positions depending on the strength of your source, the time you have available, the counting rates you want, etc.

1 Introduction

Radiation is the transmission of energy by waves and/or particles. Examples of the former are β rays (electrons and positrons), protons, and alpha particles (helium nuclei). Examples of the latter are electromagnetic, sound, and gravitational waves. In this experiment, various investigations of radiation will be made using β^- particles (electrons) and γ ray photons. The radiation is obtained from radioactive nuclei. Typical energies of particles and photons emitted by nuclei range roughly from 100 keV to 10 MeV. In this experiment the β^- particles are emitted by ${}^{90}_{38}Sr$ which has a half life of 28 y. The maximum energy of the emitted electrons is 0.546 MeV, but as in all beta decay the electrons are emitted with a distribution of energies which extends from essentially zero up to the maximum energy. Excess energy is carried off by neutrinos. The gamma rays are obtained from ${}^{60}_{27}Co$ which has a half life of 5.3 y. They are emitted with a single energy of 2.82 MeV.

The following topics will be investigated in this experiment.

- The statistics of radioactive decay.
- The attenuation of beta rays by matter.
- The attenuation of gamma rays by matter.

2 Apparatus

Particles of radiation can be detected by a number of different kinds of devices (solid state devices, scintillators, etc.) but this experiment uses the tried and true Geiger tube. See Fig. 1. A sealed cylinder has an electrically insulated wire running down the center and a thin window which the radiation can penetrate. The window might be made of plastic, beryllium, or mica. The cylinder is filled with a mixture of gases at carefully chosen pressures. The PASCO Geiger tube in this experiment has a mica window and is filled with Neon, Argon, and Halogen gases. Please exercise caution. The windows are fragile and are easily destroyed. The PASCO tube is plugged into a digital input of a SWS interface. The interface supplies +5 V to the tube which has its own power supply and the wire is made 450 V positive with respect to the cylinder. Radiation entering the tube produces ionization. The ionization electrons are accelerated in the electric field of the tube and more ionization is produced. A voltage pulse is created for each particle entering the detector. These pulses are counted, and for your apparatus, there is an audio beep for each pulse.

If radiation of constant intensity is entering a Geiger tube, a plot of the counts per unit time versus the wire-cylinder voltage will look like Fig. 2. Your tube is operated in the plateau region. In this region, at a given voltage, all the pulses have about the same magnitude irrespective of their type or energy, assuming that some ionization was produced in the first place. For voltages above the plateau region a discharge takes place which will damage the tube. For voltages below the plateau region the pulse height depends on the type of particle and the particle energy. This can be useful, but is not used in this experiment. When operating with an unknown tube, the plateau region should be determined experimentally and the tube should be operated toward the lower voltage end of the plateau. In this apparatus, the correct plateau voltage is automatically applied.

Following are good procedures for using SWS to count pulses with the Geiger tube. Plug the Geiger tube into digital channel 1 of the interface and in the right experimental set-up window drag the digital plug icon to the digital channel 1 icon. Choose "Geiger Counter" (not the "old method" one). Open a table display and choose both "count per time period" and "total counts." Click the "sampling options" button in the left experimental set-up window. Click "slow" for periodic samples. The sample time can be adjusted from 1 s to 3600 s. You will probably find useful times near the lower end for this range. Let's say you choose 5 s for the sample time. Leave the start condition as none, which means data taking begins when you click REC. If you choose "time" as the stop option the number of 5 s intervals that you count will depend on the stop time that you enter. If you choose a stop time of from 5.01 s to 10.00 s, when you press "REC" you will count for one 5 s interval. If you choose a stop time of from 10.01 s to 15.00 s you will count for two 5 s intervals and so forth. This data will appear in the Table display. Put the beta source into the tray and slide the tray into one of the slots in the housing that has the Geiger tube on top. Experiment with SWS until you can count for a given number of time intervals, with the common time of the intervals being of your choosing. For example, can you count for 20 intervals, every interval of 2 s, with the counts for each 2 s interval appearing in the table display? Note that the total counts column gives the cumulative number of counts.

Another useful stop option is "none." If chosen, counting stops when the STOP button is clicked in the left experimental set-up window. This is useful when you wish to count an approximate number of counts. When "cTotal" in the table reaches about the number of counts you want, click STOP. In this case the time for which you counted is important. Obtain this by multiplying the number of intervals counted by the time per interval.

3 Statistics and Error Analysis: Square Root Rule

The emission of particles by radioactive nuclei is a random process. If you count particles for a time period T, and do this N times, where N is a large number, you will not count the same number of particles in each period T. Let ν be the number of counts for one period T and $\bar{\nu}$ be the average of N periods. Then usually about 68% of your counts will be in the range $\bar{\nu} \pm \sqrt{\bar{\nu}}$. The probability of finding counts further away falls off exponentially if the number of counts is not too small. The standard deviation σ is defined as the root mean square deviation of ν from its average $\bar{\nu}$. It can be shown that the standard deviation $\sigma = \sqrt{\bar{\nu}}$.

If a measurement is being made in a single time period T with a count ν, the appropriate way to report your data with the uncertainty is $\nu \pm \sqrt{\bar{\nu}}$. The fractional uncertainty in the data goes as $\sqrt{\bar{\nu}}/\nu = 1/\sqrt{\bar{\nu}}$. As the number of counts increases, the uncertainty increases, and the fractional uncertainty decreases.

3.1 Geiger Tube Dead Time

When an ionizing particle enters a Geiger tube and creates a pulse, the tube will not respond to another particle for a period called the "dead time." It takes time for the ionization in the tube to dissipate and for the tube to be ready for the next particle. The dead time for the PASCO tube is 90 μs. We would expect to be able to count a maximum intensity of about 10^4 particles per second. But this is optimistic. Due to the statistical nature of the arriving particles, there are a few particles that will arrive closer together than the dead time. There is an exact formula which tells one how many pulses will not be counted, but we will omit that here. Suffice it to say that if the counting rates are kept at or below 1000 counts per second, the missed counts can be neglected.

4 Statistics Experiment

Using the β source and the Table Display, set up an experiment in which you count 5 s intervals 20 times. Move the source a distance from the Geiger tube such that in each 5 s interval you get 100-200 counts. Take the data and then click the Σ button on the Table Display so that the average and the standard deviation are calculated for you. Do the twenty counts you get lie in the expected range?

5 Attenuation of Radiation

Attenuation of radiation as it passes through matter is important for many topics such as shielding radiation sources, x-rays, tumor irradiation, and sonograms. Under special circumstances, the intensity of a directed beam of radiation will decrease exponentially with the distance as it travels through a substance. These special conditions are often not met, particularly in the experiments you are going to do. Nevertheless, it is of interest to examine this archetypal problem. See Fig. 3. A directed pencil-like mono-energetic beam of particles of intensity I particles per unit time is incident on a slab of matter of thickness dx. The matter is composed of particles each of which present an area or cross-section Q to a particle in the beam such that some kind of interaction removes the beam particle from the beam so that the beam particle does not reach the detector. Q is usually, but not always, a function of the relative speed between the beam and target particles. In traversing the slab the beam is attenuated by an amount dI. The type of interaction might be scattering or absorption. The fraction of the incident beam that will be scattered in traversing dx is $nQdx$. This assumes that that there are no multiple scatterings that will scatter particles back into the beam. This leads to $dI = -nQIdx$. Integrating this expression,

$$I(x) = I_0 \exp(-nQx), \qquad (1)$$

where I_0 is the initial beam intensity and $I(x)$ is the intensity after distance x in the matter.

6 Attenuation Of β Rays By Matter

For the β particle energies of this experiment, the primary interactions between the β particles and the solid matter are

- elastic scattering from nuclei,
- inelastic scattering from nuclei with the emission of radiation which is called Bremstralung ("braking radiation"), and
- ionization of atomic electrons.

Each electron experiences many collisions of different types, and taking into account that the β particles have a distribution of energies and that the cross sections are energy dependent, it is a bit of a fluke that the attenuation is approximately exponential with the thickness of the absorbing material. One deviation from the exponential behavior is that there is an absorber thickness for which no electrons get through.

6.1 Experiment- Beta Ray attenuation

Move the radioactive sources well away from the Geiger tube, being sure there is no source in the sample tray. Count for 2-3 minutes to obtain the background counts. These are due to cosmic rays and natural radioactivity which is in everything, including you. Convert your result to intensity, counts per second (c/s), and subtract this background intensity from your intensities you measure when using the sources.

Put the tray with the β source in it in the second slot from the top. Choose a time interval of 5 s and choose none for the stop option. Click run, and when the total number of counts is about 400 click stop. Record the counting time per interval, the number of intervals, and write down zero for the absorber thickness. Calculate the beam intensity in counts per second (c/s) with appropriate error. Subtract the background intensity.

As an example, suppose you count 476 counts in three 5 s intervals for a total counting time of 15.00 s. The total counts with error is $476 \pm \sqrt{476} = 476 \pm 21.8$. To calculate the beam intensity with error divide both the 476 and 21.8 by 15 s to get 31.7 ± 1.5 c/s. The error for the beam intensity is not $\sqrt{476/15}$. Error or uncertainty should be given to one significant figure unless the first digit is 1, in which case give two significant figures. If the background intensity is 2 c/s, the final result would be 29.7 ± 1.5 c/s.

In the following, be careful not to disturb the physical configuration of the source and Geiger tube. There are 3 types of absorbers available to you; plastic, aluminum, and lead. For beta rays, the Al absorbers have the right density. Place the lightest one, 129 mg/cm^2, on the top of the source. Count for about the same number of counts as you did with no absorber in place. Because the beam is attenuated, it will be necessary to count for a longer time and the calculated beam intensity will be lower. As always, correct for the background.

Repeat the above procedures, using thicker absorbers.

6.2 Data Analysis

Plot ln (*beam intensity*) versus absorber thickness. Use your calculator to evaluate the ln's and use ordinary graph paper. You can also plot the uncertainties. Let I be a beam intensity and δI its uncertainty. The point itself would be given by $\ln I$. The two points denoting the uncertainty would be given by $\ln(I + \delta I)$ and $\ln(I - \delta I)$. Discuss your results. Do you think your points lie close enough to a straight line to justify calling the attenuation exponential with absorber thickness?

7 Attenuation Of γ Rays By Matter

Gamma rays, or high energy photons, are attenuated by matter by the photoelectric effect, the Compton effect, and pair production. While all these effects are always present, at lower energies ($\sim 0.1\ MeV$) the photoelectric dominates, at intermediate energies ($\sim 1\ MeV$) the Compton effect dominates, and at higher energies pair production dominates.

- The photoelectric effect is an interaction between a photon and an entire atom. The incident photon is completely absorbed and an electron (usually a K or L electron) is ejected from the atom. The remaining atom recoils.
- The Compton effect is the elastic scattering of a photon from an essentially free electron. The energy of the scattered photon is lower than that of the incident photon, with the scattered electron taking up the energy difference.
- Pair production occurs usually in the electric field of a nucleus. The photon is completely absorbed and a positron-electron pair appears.

8 Experiment- Gamma Ray Attenuation

Using the gamma source provided, design, carry out, and analyze an experiment on the attenuation of gamma rays. You will find that the Pb absorbers are appropriate for this experiment.

9 Comments On Biological Effects Of Radiation

When radiation enters your body, your body absorbs energy from the radiation. The "dose" is the energy absorbed per unit mass by your body. The dose in itself is not a complete indication of how much damage has been done to your body by the radiation. The dose is multiplied by Relative Biological Effectiveness (RBE) which gives the equivalent dose. Very approximate values for the RBE's of various types of radiation are given in the following table The equivalent dose is a measure of how detrimental biologically the dose is. The

RBE's are approximate and have an energy dependence.

Radiation	RBE
x rays and gamma rays	1
electrons	1.0-1.5
slow neutrons	3-5
protons	10
alpha particles	20
heavy nuclei	20

Note how damaging alpha particles are relative to photons. Uranium in rocks slowly decays, by a series of decays, into the radioactive gas radon-222. The radon decays by emitting an alpha particle. If it does so in your lungs, in addition to the emmitted alpha particle from the radon the daughter nucleus is polonium-218, which is also an alpha emitter. There are a further series of daughter nuclei all of which stay in your lungs and many of which are alpha emitters. This is one of the main "background" radiations we are exposed to.

10 Questions

1. Why do you think x-rays and not beta rays are used for peering into the human body?

2. If you are doing a radioactive counting experiment, and want to change the fractional uncertainty in your data by a factor of 1/3, by what factor do your counting times have to change?

3. What would be the minimum energy of a photon necessary to produce an electron-positron pair? Give your answer in MeV.

11 Finishing Up

Please unplug the Geiger tube from the interface and leave the bench as you found it. Thank you.

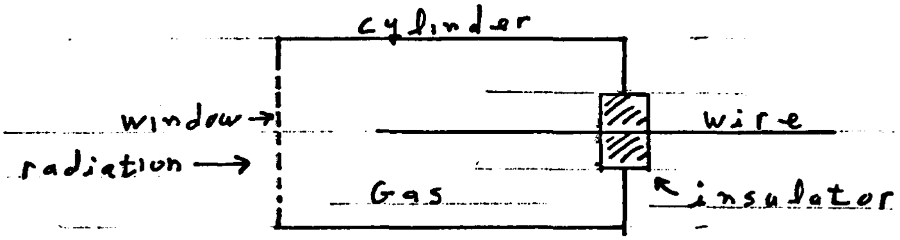

Fig. 1

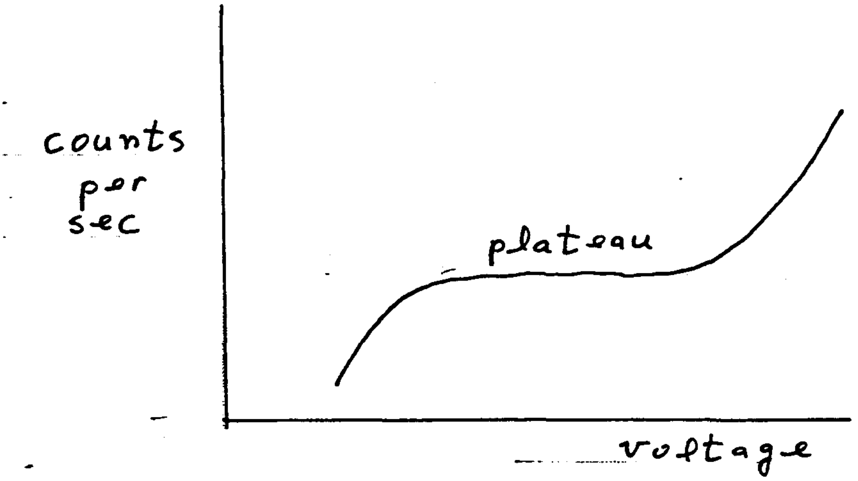

Fig. 2

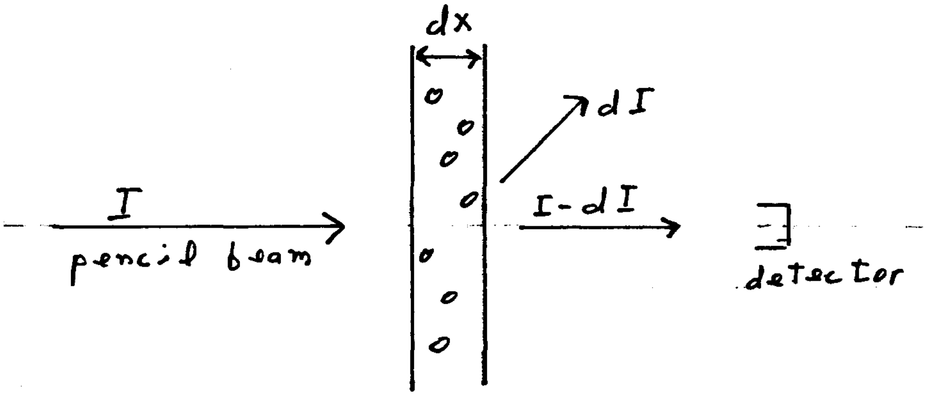

Fig. 3