RADIOACTIVITY IN THE AIR

REFERENCES

M. Sternheim and J. Kane, *General Physics* (See the discussion on Half Life)
Evans, *The Atomic Nucleus*, pp. 518-522
Segre, *Nuclei and Particles*, p. 156

See *HEALTH AND SAFETY IN THE LABORATORY* in the **Laboratory manual** with regard to handling radioactive materials and lead. In particular, not the following cautions on radiation: The sources we use in the lab are weak, so that when properly used, they subject the user to a small fraction of the radiation one receives in every-day life. However, as with any toxic material, it is important that you minimize the exposure you receive as any exposure does damage (be it small) to your body. Thus, place the sources you are using in a location away from yourself and other persons. Total radiation exposure is proportional to the source strength, the time you are exposed and a distance factor which for gamma rays drops off as the inverse square of the distance, and for alphas and betas, even faster.

INTRODUCTION

This experiment involves filtering atmospheric air using the provided blowers, and then measuring and identifying the radioactive substances deposited on the filter (available at the **R**esource **C**entre). The blower is placed outside. The results, both amount and type of radioactivity, generally depend on the length of time for filtration, and on the weather conditions on a given day.

The experiment is carried out with a Geiger-Muller counter. One should therefore first find the high-voltage range where the counting rate shows little variation with the applied high voltage (this is best done with the help of a graphic) and work in the middle of this range.

When this experiment was done in the early 1960s, the radioactive materials picked on the filter paper included A-bomb products ^{90}Sr, ^{131}I, etc.), often in quite large amounts. In fact, there were networks of air and rain sampling stations around the world, and the fallout from an atmospheric test could easily be traced as it drifted around the world. More recently, following the Chernobyl accident on 26 April 1986, air samples taken here in the Physics Department were found to contain ^{137}Cs, ^{134}Cs and ^{131}I. (These products arrived quite suddenly on 11 May 1986.) With the ban on atmospheric testing being more or less successful and with the current absence of nuclear accidents, the radioactivity you will measure is probably completely natural and has been around the environment for billions of years.

The three natural radioactive families you are likely to observe originate with the isotopes ^{238}U, ^{232}Th and ^{235}U. All three occur naturally with half-lives greater than the age of the earth. They each decay through a long chain of radioactive daughters, ending with stable ^{206}Pb, ^{208}Pb and ^{207}Pb respectively. The members of the chain may be determined from the Chart of the Nuclides posted in the lab, or from any number of texts (see the Evans or the Segre reference). The identification of the radioactive isotopes in your sample hinges on two criteria: the measured half-life and the type of radioactivity, alpha or beta.

The results of your experiment will depend in part on how long the filtration is carried out. What is actually being measured here is the radioactivity of dust particles, and in a long filtration the short half-life daughters already deposited on the filter will decay. See Figure 1.

The rate at which ^{218}Po etc. (which are metallic atoms or ions) will accumulate on dust particles also varies according to the availability of dust or smog. Thus in very clear conditions one might expect most of the ^{218}Po to α decay to ^{214}Pb without first becoming attached to dust since the half-life is only a few minutes. There will then be relatively more accretion of ^{214}Pb and ^{214}Bi onto atmospheric dust. On the other hand, under very smoggy conditions there will be much more ^{218}Po accretion on dust, and most of the observed radioactivity from filtered air may be decays from the filtered ^{218}Po. The *proportions* of ^{218}Po, ^{214}Pb, ^{214}Bi which are found *initially* the on filter may thus vary according to atmospheric conditions.

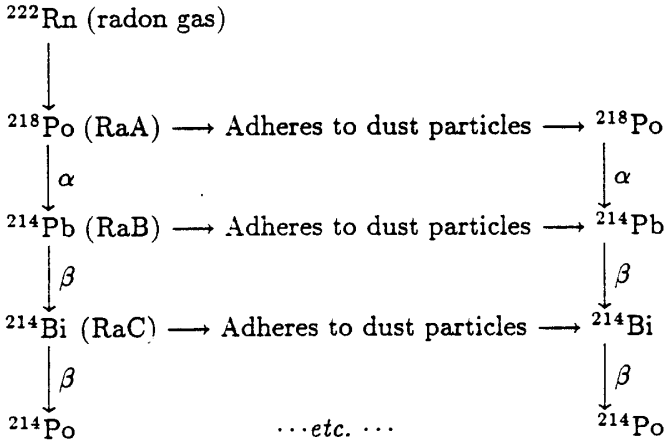

Figure 1: Model of the successive radioactive decays from ^{222}Rn as far as ^{214}Po. The series terminates at ^{206}Pb which is stable.

PRELIMINARY EXERCISES IN NUCLEAR COUNTING

NUCLEAR RADIATION DETECTORS

GEIGER-MUELLER TUBES: These are gas filled counters with an applied high voltage large enough that electron and ion multiplication takes place, so that every time ionizing radiation passes through the counter and produces ionization, there is a measurable negative charge accumulated on the centre wire anode. [With the anode connected through a resistor to the power supply, a negative voltage negative pulse appears at the anode when an ionizing particle passes through the tube. There are two types of Geiger-Mueller tubes which are in use in the laboratory. The ones made by *Nuclear Chicago* require about 950 V across them. The TGM tubes however operate at a voltage of about 1400 V. check the kind of tube you have and apply the required voltage.

THE PICKER SCALER: This provides a high voltage power supply for the G-M tube, in addition to being a counter. The Picker Scaler block diagram is shown in Figure 2. All the components inside the solid line are inside the box of the scalar. The 4 connectors at the back of the scalar correspond to those labeled on the figure.

EXERCISE 1

Observe the construction of the G-M tube. Note the thin window at the end. BE CAREFUL NOT TO DAMAGE IT. This window has a thickness of between 1.4 and 2.0 mg/cm^2 which is thin enough to pass beta particles, but is thick enough to stop alpha particles of energy less than about 2 MeV. The gas is not very efficient for being ionized by γ rays so that this counter is most useful for beta particle detection.

Place a ^{137}Cs source in front of the GM counter, and connect it to the picker scaler *detector input* terminal with the high voltage set to the working value. Using the oscilloscope, observe the GM pulses appearing at the *pulse input* terminal. Note their voltage, shape and length. Note the effects of moving the source closer to and farther from the counter. Note the randomness of time of arrival of the pulses. Note the effects of varying the high voltage. Note the time the GM tube is "dead" after a pulse is produced. What is the "dead time" of this counter? Connect the oscilloscope to the *output pulse* terminal and observe the standardized pulse that the discriminator produces. (See Figure 2).

CAUTION: Some of the Picker scaler connectors have high voltages on them, sufficient to damage an oscilloscope input. Be extra careful in connecting the oscilloscope to the *pulse input* terminal. Moreover, connect the oscilloscope to the Picker scaler *pulse input* terminal only after the Picker scaler has been set into operation. Also, do not switch the picker scaler high voltage setting while the oscilloscope is connected. When in doubt, consult a demonstrator.

EXERCISE 2

Determine the operating voltage of the GM tube by taking a plateau curve. (The oscilloscope should not be connected in this section). With a source near the front of the GM tube, measure and plot a curve of number of counts per standard time interval *versus* high voltage. The horizontally flat portion of this curve is called the plateau. The operating voltage should be taken in this region where counter sensitivity is independent of high voltage.

NOTE: In doing this exercise, make sure that you count long enough at each voltage setting, in order to make sure that counting statistics allow adequate determination of the count rate. In drawing your plateau curve, include error bars, using as a guide the statement that the standard deviation in the number, *N*, of random events observed is equal to the square root of N.

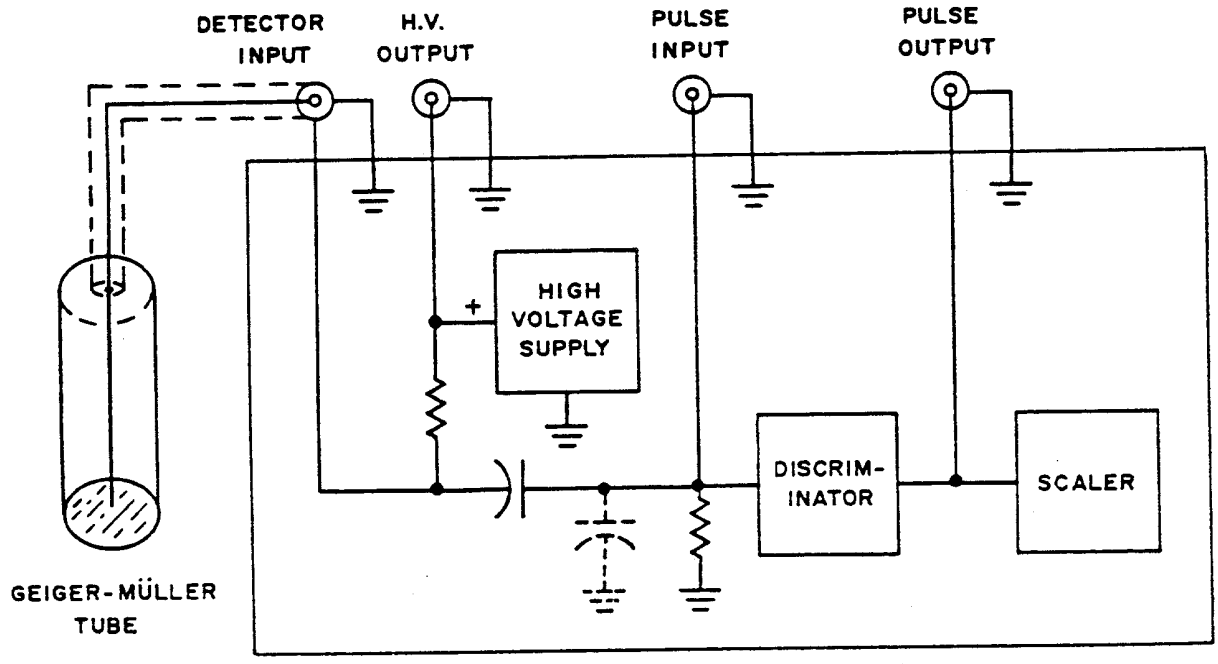

Figure 2: Picker Scaler Block Diagram

THE EXPERIMENT

BACKGROUND COUNT RATE

In all nuclear counting experiments there is a small "background" count rate due to the presence of small amounts of radioactive materials in the ground and building walls due to cosmic rays. You should always try to reduce this background as much as possible by shielding your detector and by keeping your own and your neighbor's unwanted sources far from your detector.

Since the amount of radioactivity in your sample is likely to be small, it is essential to determine the background (no sample) count rate accurately. Be sure to determine the background under identical conditions to those you will be using for your measurements, and count long enough to reduce the error in the background to ≤ 1 count per minute. In other words, since the error on n counts is $\sqrt{n}$ counts, if the background count measurement lasts m minutes, $\frac{\sqrt{n}}{m}$ should be below 1. You will probably find that this requires a counting time of 20 minutes or so.

ALPHA OR BETA?

Alpha decay radioisotopes are not common in this experiment, but may be present. They may be identified by the fact that a thin foil of Al, or a few centimeters of air, will stop the alphas entirely.

If alphas are present, then beta activity will also exist in the sample. Thus, you will need to separate these two activities. This is made more complicated by the process of build-up. For example, if you have ^{218}Po in your sample, it alpha decays to ^{214}Pb with a half-life of 3 minutes. But, the ^{214}Pb then beta-decays to ^{214}Bi with a half-life of 27 minutes.

$$^{218}\mathrm{Po} \xrightarrow[\alpha,\ 3\ \mathrm{m}]{} {}^{214}\mathrm{Pb} \xrightarrow[\beta,\ 27\ \mathrm{m}]{} {}^{214}\mathrm{Bi}$$

Thus as the α activity goes down, the β activity goes up. In this example, the Bi then β decays with a half-life of 20 minutes. What effect might this have on your measurements?

DETERMINING THE HALF-LIFE

Essentially, the count rate, $\frac{dN}{dt}$, must be determined as a function of time.

A plot of $ln(\frac{dN}{dt})$ versus t will allow you to find the half-life.

The result of your first couple of measurements will allow you to decide on the appropriate counting procedure. The length of time to be used for doing the count must be much less than the half-life being measured. It may also be worthwhile to check the activity of your sample 24 hours later to detect any long-lived isotopes.

(dh - 1976, jv - 1990)