Practical Experiment (A) - PY3011

Detection of Natural Radioactivity: ^{222}Radon

Learning Objectives:

- Gain knowledge about the basics of natural radioactivity.
- Work with a simple set-up for detecting radioactive decays (Geiger-Müller detector).
- Learn how to determine the effective half-life from measured count rates. - Interpret measured data correctly.

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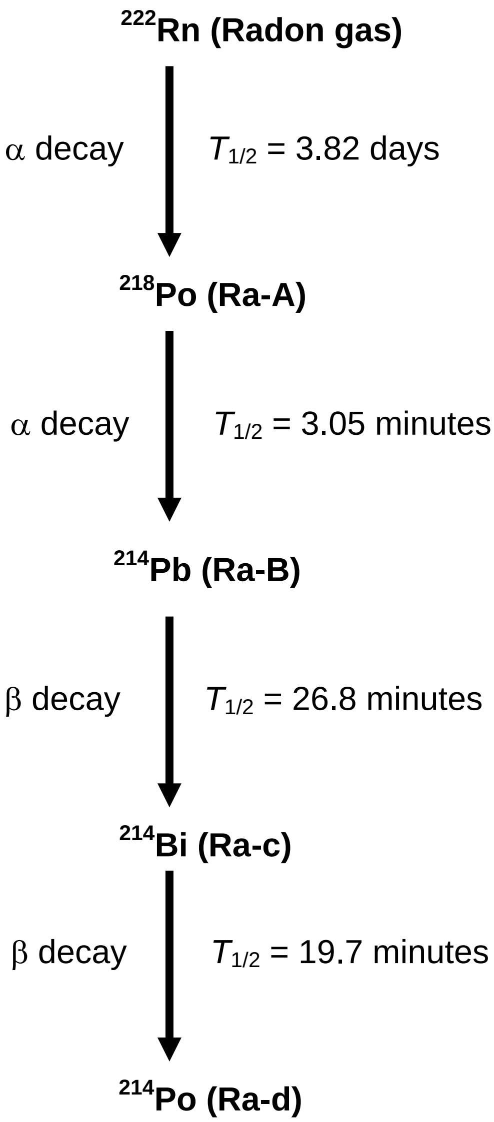
1. Introduction: Radioactivity all around

We live with radioactive radiation every day. Depending on the origin of the radiation one can distinguish between natural radioactive sources as well as man-made sources. Typical examples of man-made sources are radioactive isotopes for medical diagnosis and therapy (15%), consumer products such as televisions, luminous dial watches and smoke detectors (3%), atmospheric testing of nuclear weapons and nuclear power plants (<1%).
Radioactivity in nature comes from three main sources, cosmic particles/radiation (8%), internal sources in the human body, (11%) and terrestrial radioactivity (62%). Terrestrial radioisotopes in the crust of the earth came into existence with the creation of the planet. Although some have long disappeared to levels that are not detectable anymore, some radioisotopes take a long time to decay (on the order of hundreds of millions of years), they are still present today.
Examples of radioisotopes found in rock, soil, water, air, and in food are ^{14}carbon, ^{40}potassium, ^{223}thorium, ^{238}uranium, ^{218}polonium, and tritium (^{3}hydrogen). These elements have not yet decayed to a stable, non-radioactive isotope such as ^{206}lead.
By far, the largest contributor to our daily exposure to radioactivity in the environment (54%), and the major form of natural high-energy radiation is the noble gas radon. ^{222}Radon is a naturally occurring decay product of ^{238}uranium, which is commonly found in soils and rocks. ^{222}Radon is odourless, colourless, tasteless and chemically non-reactive. As it escapes from the soils and rocks where it is trapped, it enters the water we drink and the air we breathe.

Since distribution of uranium in the earth's crust varies from place to place, so does the prevalence of radon gas. In areas where surface rocks contain a high concentration of uranium, radon gas could enter a home through a crack in the foundation. A concern for homeowners is the possibility that radon gas could accumulate to dangerous levels. This is especially a problem during the winter months when windows and doors are tightly shut.

The decay of Radon gas into its daughter particles is shown in the decay series below:



It has been shown that in air 50% of the daughter products of radon are attached to positively charged aerosol particles. Rutherford demonstrated that these particles could be collected from the atmosphere by electrostatic attraction, an approach taken in this practical. To collect aerosol particles (and hence the Radon daughter particles attached to the aerosols) from ambient air, a 4 metre long enamelled wire is put on a –25 kV potential with respect to ground for a period of about 2 hours (started before the practical lab). During this time, aerosols are attracted to the wire and stick to its surface.

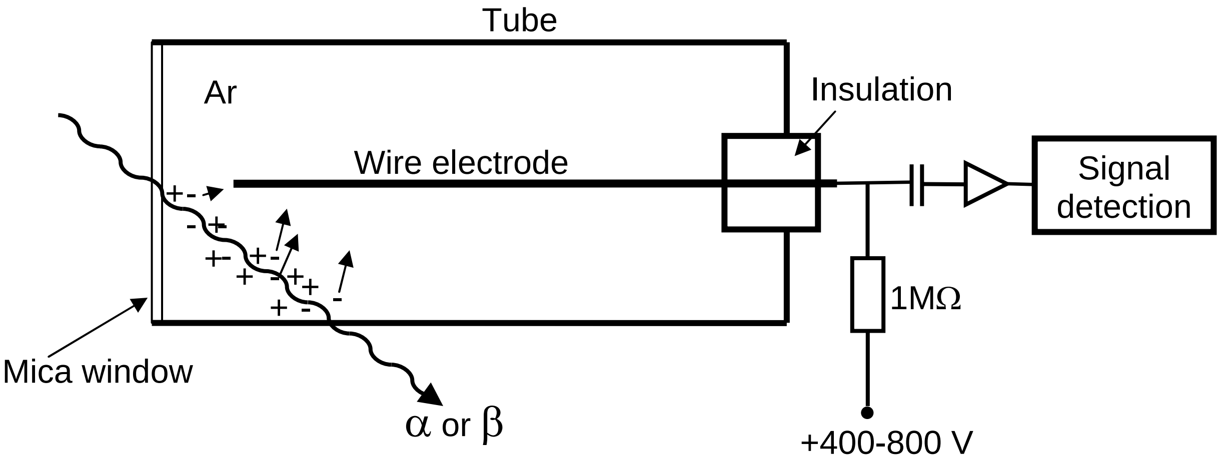
References and further information

- Radiation Protection, U.S. Environmental Protection Agency (www.epa.gov/radiation/index.html);
- The Health Physics Society, The University of Michigan (www.umich.edu/~radinfo/introduction/natural.html);
- Nuclear Energy Institute (www.nei.org/index.asp?catnum=2&catid=54; www.nuclearsite.com).

2. Detecting Radioactivity: The Geiger-Müller counter

The number of nuclear decay events will be measured using a RM-60 Micro-Roentgen Radiation Monitor. This is a highly sensitive, easy to use so-called *Geiger-Müller counter*, which is interfaced to a PC computer. The RM-60 can detect all three types of radiation emitted by radioactive materials, namely alpha (α), beta (β), and gamma (γ) radiation, as well as X-ray radiation. The system can detect and display dosage levels between 1 and 3×10^4 microroentgen/hr.

The basic set-up of a Geiger-Müller counter, which are widely used for the detection of radioactivity is shown below:



The counter consists of a tight gas filled tube with a wire mounted inside. The gas is eitehr a halogen or a noble gas, e.g. Argon, at low pressure. A high electrical field between the wire and the housing is generated by applying a high positive voltage (+) to the wire. When high-energy radiation enters the tube it ionises atoms in the gas (primary ionisation), which consequently gives off electrons. The free electrons are then attracted to the positively charged wire (electrode) in the centre of the tube. Due to the high voltage electrons are strongly accelerated towards the wire. On their path they collide with other gas atoms, which release more electrons from the gas atoms, this process is called secondary ionisation. The secondary ionisation causes an avalanche effect, which generates an easily detectable pulse of current, which is measured in the counter as an "entry event". The pulses are then counted as a function of time. In many cases a "count" is also converted into an acoustic click of sound. The entrance window of the tube is made of mica, since this material allows weak α particles to penetrate the tube. Some Geiger-Müller counters do not have this feature and are only sensitive to β- and γ-Gamma radiation depending on the material used in the entrance window. They are constructed of specially coated stainless steel, mica and ceramic. Joints are normally fused shut in a furnace with molten glass, they can be very rugged. The RM-70 includes a screw-on stainless steel wire mesh cover to help protect the mica window from damage.

The counting efficiency for any charged particle, including α and β, that enters the active volume of the tube is essentially 100%, therefore the effective counting efficiency is determined by the probability that the incident radiation penetrates the tube window.

Note: Because Geiger-Müller counters only register general ionisation, they cannot be used to distinguish between the various types of ionising radiation. Their efficiency for γ radiation is usually very low (<1%). Specifications of the counter used in the experiment are listed in the Appendix (for more information on the RM-60 Micro-Roentgen Radiation Monitor and software see http://www.aw-el.com/index.htm).

3. The AWARE (Geiger counter) software package

To open the AWARE software package double click on the 'shortcut to AW-RADW' on the desktop.

Before starting to count the following menue points should be set. Select
'Output Options' - **'Screen Options'** - **'Draw ASCII File Format to Screen'**,
'Output Options' - **'ASCII Text File Options'** - **'ASCII Delimiter Character'** - **'Tab'**,
'Output Options' - **'ASCII Text File Options'** - **'ASCII File time code'**- **'s-Seconds since 1/1/1970'.**

In order to start collecting data select **'Rad Collection'** – **'Express start collection of Rad data'**. The computer will now prompt you for a **'Select Aware Binary Rad Data File'**. Click on **'Cancel'**. Next the computer will prompt you to enter a file name for your data in the form **'Aware ASCII Output File'**. Create your own **'file name'**.dat. When you click **'OK'** in this window the program will start collecting data.

To stop the count select **'Rad Collection'** – **'Stop Collection Of Rad Data'**.

Optionally (not needed for experiment): If during collection of data you want to extract some of the data already collected by the counter, select **'screen'** – **'copy'** – **'copy screen to clipboard most recent at bottom'**. This will copy all the information displayed on the entire screen, including comments and status lines. The data can then be pasted into Notepad or an Origin7.0 worksheet for further analysis.

4. The effective half-life of the Radon daughter particles

The half-life of the decay ^{222}Rn → ^{218}Po of 3.82 days is too long in order to be measured in this experiment. The half-life, which will be measured, is the *effective* half-life of the combination of half-lives of the daughter Radon elements ^{218}Po, ^{214}Pb, ^{214}Bi, ^{214}Po – it is of the order of 45 mins. The number of Radon daughter nuclei, N, at any time t is given by the radioactive decay equation:

$$N = N_0 \exp(-\lambda t) \qquad (1)$$

Where N_0 is the number of Radon daughter nuclei present when counting (with the Geiger counter) commenced (t = 0), and λ is the disintegration constant of the daughter nuclei, which is directly related to the half-life $T_{1/2}$ by the equation:

$$T_{1/2} = (\ln 2)/\lambda \qquad (2)$$

The recorded count rate, C, is directly proportional to N so that we can write

$$C = C_0 \exp(-\lambda t), \qquad (3)$$

where C_0 is the count rate at $t = 0$. Thus

$$\ln C = \ln C_0 - \lambda t \qquad (4)$$

The AWARE software records the count rates C at ten second intervals. Using this data a plot of ($\ln C$) versus time produces a line with a negative slope of λ. Use λ to calculate $T_{1/2}$.

5. Error analysis

It can be shown that the standard deviation of the count rate C is given by $\sqrt{C}$. Thus the error on a count rate of 10,000 is 100 (1%) whereas the error on a count rate of 100 is 10 (10%). This means that the percentage error attached to count rates towards the end of the hour period over which readings are recorded is substantially greater than the percentage error attached to count rates at the beginning of the period. Readings at the beginning should therefore be given more weight (i.e. smaller error bars) when determining the slope of the graph.

The length of an error bar $\Delta(\ln C)$ for a particular value of $\ln C$ may be determined in terms of the error bar in C,

$$\Delta C = \sqrt{C}\,, \qquad (5)$$

through differentiation.

Using the standard derivative, $d(\ln x) = \frac{dx}{x}$ we obtain $d(\ln C) = \frac{dC}{C}$,

thus $$\Delta(\ln C) = \frac{\Delta C}{C} = \frac{1}{\sqrt{C}}\,. \qquad (6)$$

6. The energy spectrum of the radiation *(not in this practical)*

The aerosol particles collected by the wire contain many different sources of radiation. The Geiger counter counts all the emitted particles (β, α) by the collected sources of radiation but does not distinguish which particle is emitted by which source. This is why only the effective half-life of the culmination of isotopes is calculated using the Geiger counter.
To show the many different decays involved a multichannel analyser can be used.

7. Experimental Procedure and Tasks

Part I: The background radiation

A) Measure the background counts per second using the AWARE software package as described, counting the background radiation at ten-second intervals over five minutes. Find the average count-rate [s^{-1}], in a ten-second interval. This is the background count-rate.

Part II: Investigating natural sources of radiation found in a regular home and outdoor environment

Before analysing Radon gas collected in the air other samples of naturally occurring radiation can be examined, such as

A) **Smoke alarm:** A smoke detector contains the radioactive source, ^{241}Americium, which emits alpha particles and low energy gamma rays (60 keV, giving a dose at 1 metre of 0.0011 mSv/yr). The alpha particles are absorbed within the detector, while most of the gamma rays escape harmlessly. The alpha particles emitted by the ^{241}Am collide with the oxygen and nitrogen in air in the detectors ionisation chamber to produce charged particles called ions. A low-level electric voltage applied across the chamber is used to collect these ions, causing a steady small electric current to flow between two electrodes. When smoke enters the space between the electrodes, the alpha radiation is absorbed by smoke particles. This causes the rate of ionisation of the air and therefore the electric current to fall, which sets off an alarm.

The alpha particles from the smoke detector do not themselves pose a health hazard, as they are absorbed in a few centimetres of air or by the structure of the detector.

- Verify the “distance square law” shown in the lecture. Measure the activity of the source from the smoke detector at different distances between 1 cm and 10 cm in steps of 1 cm. Use a clamp and stand and a meter stick for this purpose. Import the data into Origin7.0 and plot activity versus distance.

- Also measure the activity of the smoke alarm in its normal casing for 5-10 minutes and calculate the average count rate over the ten-minute period. Import the data into Origin7.0 and calculate the average count rate over the time period you measured.

Source and for more information: Uranium Information Centre, Melbourne, Australia
http://www.uic.com.au/index.htm

B) **Computer monitor screen:** The static charges on a computer screen attract radon daughter products (^{218}Po, ^{214}Pb and ^{214}Po) from air in the same way as a wire connected to a –25 kV voltage.

Place the Geiger-Müller counter on a stand in front of a monitor screen, with the wire mesh facing the computer screen and the Geiger counter touching the screen. Measure the radiation count rate emitted by the computer screen for a 5- 10 minute period. Import the data into Origin7.0 and calculate the average count rate over the ten-minute period.

C) **Natural Uranium** ***(not in this practical)*****:** A source of natural Uranium rock found in Donegal is available in the lab. Place the source over the Geiger counter and measure the radiation count rate emitted by the Uranium ore for a ten-minute period. Import the data into Origin7.0 and calculate the average count rate over the ten-minute period.

Part III: Study the radiation from Radon daughter products

A) The aerosol particles (and hence the Radon daughter particles attached to the aerosols) are being collected on a 4m long enamelled wire that is attached to a –25 kV potential for a period of about 2 hours. Care must be taken when using the –25 kV voltage, as it will give off a large shock. At the end of this period, when enough aerosol particles have been collected from the air, the enamelled wire is disconnected from the high voltage supply. Make sure not to touch the wire when disconnecting it from the voltage. Use a ruler or piece of wood to disconnect it – why…?

B) Once the wire is disconnected use an appropriately sized piece (the same surface area approximately as the Geiger counter) of tissue to clean the aerosols off the wire.

C) The tissue should now contain much of the ^{222}radon and its daughter particles, which were attached to the wire. Place the contaminated tissue on a Geiger-Müller counter. Make sure that no dust from the wire is allowed to slip through the wire mesh protecting the Geiger counter by placing a thin piece of tissue between the Geiger counter and the radon source.

D) Use the AWARE software package to measure the count rate C at ten-second intervals for a period of an hour as described above (Part II).

E) After an hour stop collecting data. Import the data collected into Origin7.0 as described in the Appendix.

F) Using Origin7.0 as described in the appendix, plot a graph of ln C versus t. The slope of this ('linear') graph can be used to determine λ and, from this, $T_{1/2}$, the effective half-life of the radon daughter particles for the hour.

Part IV: Write a report

A) Write a report giving background information on natural radioactivity, describe the experiment and outline the results – add graphs (including error bars).

B) Verify the distance square law by plotting the activity versus distance. Give an explanation of difference in activity recorded at different distances between the counter and the source. Also determine the significance of the average count rates recorded from the encased smoke alarm. Was any decay noticeable when recording the count rates? Explain your observations.

C) Determine the significance of the average count rates obtained from the computer screen (with regard to the standard deviations of the background count and the smoke alarm counts). Discuss the observed difference between the smoke alarm count and this experiment. Was any decay noticeable when recording the count rates? Explain your observation.

D) Plot a linear graph of counts over a ten-second interval versus time for data collected with radon radon (for one hour). Plot a graph of ln(counts over a ten-second interval) versus time for data collected for a hour). Determine the effective half-life and describe the method to determine half-lives. Discuss the errors of the measured quantities.

Appendices

A1. Using Origin7.0

1) To open Origin7.0, double click on the **"shortcut to Origin70.exe"** icon on the desktop.

2) Import the data into Origin7.0 by selecting **"file" – "import" – "single ASCII"**. The computer will now prompt you for a file name. Select your 'file name'.dat of the data measured with the AWARE software.

3) Alternatively: To paste data into Origin7.0 select **"edit" – "paste"**

<u>To determine the average of the background count rate:</u>

4) Highlight column B(Y) by clicking on the B(Y) column title. Select **"analysis"** on the Origin menu list and click on **"statistics on column"**. Origin now will create a window displaying all the statistics of the column including the mean and the standard deviation.

<u>To generate a semi-logarithmic plot:</u>

5) To open a new worksheet, select **"file" – "new"** on the Origin menu list. Origin will now prompt you to select a type of window. Select **"worksheet"** and then click on **"OK"**.

6) Import the data into Origin7.0 the same way as the background radiation data was imported.

7) Add two new columns by selecting **"column" – "add new columns"**. Origin will now prompt you for the number of new columns you need. Enter 2 and click on **"OK"**.

8) Highlight column **"B(Y)"** and then select **"column" – "set column values"** on the Origin menu list. Origin will now prompt you to set a value for column B(Y). In the box provided type **"col(B) – P"**, where P is the value that you obtained as your background count. Then click on **"do it"**.

9) The time in column A(X) is the number of seconds since 1/1/1970. To make these times more relevant, highlight column **"A(X)"** and then select **"column" – "set column values"** on the Origin menu list. Origin will now prompt you to set a value for column A(X). In the box provided type **"col(A) – (P – 10)"**, where P is the very first value in column A(X). Then click

“do it”. Column A(X) should now contain data starting at a time of 10 (seconds) and increase in ten second intervals.

10) Highlight column C(Y) and select **“column” – “set column values”** on the Origin menu list. Origin will now prompt you to set a value for column C(Y). In the box provided type **“ln(col(B))”**. While C(Y) is still highlighted select **“column” – “set as X”** on the Origin menu list.

11) Highlight column D(Y) and select **“column” – “set column values”** on the Origin menu list. Origin will now prompt you to set a value for column D(Y). In the box provided type **“1 / sqrt(col(B))”**. While D(Y) is still highlighted select **“column” – “set as error bars”** on the Origin menu list.

12) Remove any highlighting of columns by clicking right of column D(Y) into the worksheet window. Then select **“Plot” – “Scatter”** on the Origin menu list. Click on A(X) and then on the arrow X-button to make this column your x-axis. Click on C(Y) and then on the arrow Y-button to make this column your y-axis. Click on D(Y) and then on the arrow Er(Y)-button to make this column your error bars in the y-direction.

13) Change any features (axis titles, scaling etc.) of the plot by clicking on it in the graph window. Origin works screen oriented in the graphic mode. Object can modified by clicking on them.

To fit the exponential decay:

14) Select ***“tools”*** on the Origin menu list**.** Then choose ***“linear fit”.*** Click on ***“fit”.*** Examine the linear plot of experimental data with respect to the position of the error bars.

15) Use the parameter B in the fit result window (which will be a negative value, due to the decrease of counts with time) to determine the *effective* half-life of the radon decay.

A2. Specifications RM-60 or RM-70 (7231 tube)

Case material: ABS material with flame retardant and threaded brass inserts.
Case size: 4.4" × 2.44" × 1.06".
The front cover contains a 1.5" diameter threaded stem projection, in which a pancake style Geiger tube is mounted.

Window	Areal Density:	1.5 to 2.0 mg/cm^2
	Eff. Diameter:	28.57 mm
	Area:	641.08 mm^2
	Material:	Mica
Wall	Thickness:	1.52 mm
	Eff. Length:	12.19 mm
	Eff. Diameter:	28.6 mm
	Material:	446-SS

Nominal cpm/mR/hr for Cs-137: 1490

Gamma and X-ray sensitivity: less than 10 keV through end window, 40 keV through case.
Alpha sensitivity: less than 2.5 MeV; 80% at 3.6 MeV.
Beta sensitivity: 35% at 50 keV; 95% at 300 keV.