Radioactivity

Physics 246

Part A: Statistical Nature of Radioactive Decay

The purpose of this experiment is to observe the statistical nature of radioactive decay. Since radioactive decay is used as a power source, used during medical procedures, and a heat source found in terrestrial planets, how atoms decay is of interest to scientist in many fields. Atoms that go through decay can come from natural sources as well as be man-made. Today we will examine natural decay of potassium found in bananas. In particular, we will measure the radioactive decay rate of a naturally radioactive element, potassium, and observe the statistical distribution of the decay rate.

Certain elements are naturally radioactive. They spontaneously change into other elements by emitting radiation. The radiation may be an energetic photon (gamma), an electron or positron (beta), or a helium nucleus (alpha). The law governing the rate of this disintegration, the radioactive decay law, varies from element to element and is characteristic of a given element.

The radioactive decay rate is defined as $\frac{\Delta N}{\Delta T}$, where ΔN is the number of nuclei disintegrating in the time interval. ΔT. In general, the decay rate is a function of time. Thus, if we took a given sample of radioactive material and measured its decay rate today, and then repeated the measurement a month from today we would get different values. However, for some elements the decay is so slow that the quantity $\frac{\Delta N}{\Delta T}$ can be regarded as a constant over a short time interval (such as 1 month).

The radioactive decay law is of a statistical nature. This means that the law cannot predict when the nucleus of a single radioactive atom will disintegrate. For a very large number of atoms, the law accurately predicts (within a range) how many of these will disintegrate in a given time interval but it cannot be used to determine which atoms will disintegrate and which will not. It can only state the probability that an atom in the ensemble of atoms will decay in a given time interval. The law is accurate for a large number of atoms. It becomes less and less accurate as the number of atoms decrease.

The statistical nature of the decay law can also be described in another way. We will refer to the number of counts recorded in a given sample period as N. We then repeat the measurement again and again. We will find that the values of N will vary from measurement to measurement because of the statistical nature of the decay counts. However some values will occur more frequently than others. If we plot the number of times a given value occurs (the frequency of the N) versus the value for N (number of counts), we obtain a bell shaped curve, like the one seen in Fig. 1.

The radioactive decay law will provide the most probable count N_{avg} that will occur most frequently only if a sufficiently large number of measurements are taken. Statistics predict that the standard deviation will theoretically be $\sigma = N_{avg}^{1/2}$. The shape of the curve is actually a Poisson distribution but if $N_{avg} > 20$, it can be approximated by a Gaussian function (Equation 1) that gives the probability P of measuring a particular count, N.

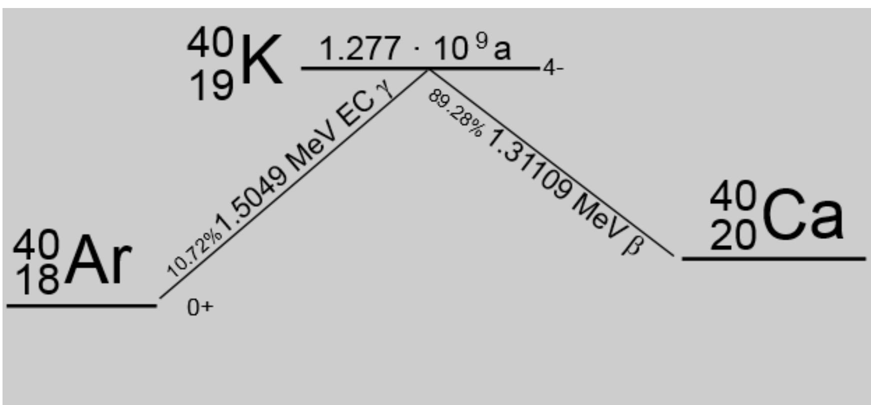
Part A Procedure:

In this experiment we will use background radiation to produce a histogram of decays over approximately 20 minutes. Since background radiation is assumed to be essentially decaying at a constant rate (thus the rate is sufficiently small to be considered constant over data taking interval) and we will study the statistical distribution of the counts for a certain period of time. The background is from a combination of cosmic rays from space and natural radioactivity from materials such as concrete in the building.

We will also surround the Geiger counter with bananas. Bananas have a high level of Potassium and therefore a very small percentage of these Potassium atoms will be radioactive There are actually three potassium isotopes: K39, a stable isotope, is the most abundant, at 93.26 % of the total; K41 is next in abundance at 6.73 % and is also a stable isotope. Radioactive K-40 has an isotopic abundance of 0.01% and a half-life of 1.25 billion years. The average banana contains around 450 mg of potassium and will experience about 14 decays each second. This is not something to worry about you already have potassium in your body, 0.01% as K-40.

The Geiger counter is used to detect the radiation from these various sources. You should take a count for 5 minutes to get the average room background count. Then you will to place the bananas around the Geiger counter and start an hour run while you work on Part B.

Potassium decay will follow the figure below, mainly decaying into Ca through a beta decay:



1. Start Capstone and connect the Geiger counter to Data Channel 1. Open the Geiger Counter Properties and set the data rate to Slow at 1 sample per 30 seconds. In this setting Capstone will count the signals from the Geiger counter for 30 seconds, record that value, and then zero the number and start counting over again.

2. Drag the histogram and table icons up to Geiger Counts in the data section and you are ready to take data.

3. Press Start and a histogram will start to accumulate. Let it run for about 5 minutes or 10 30-second counts. From the histogram, calculate the average count per 30 second period. Record this count which is from room background and clear the histogram.

4. Place the radioactive bananas as close to the Geiger counter as possible. Press Start and a histogram similar to Fig. 1 will start to accumulate. Click on the histogram icon above the graph to set the bin size to one. **Once you are sure it is counting correctly, minimize Capstnoe and work on Part B.**

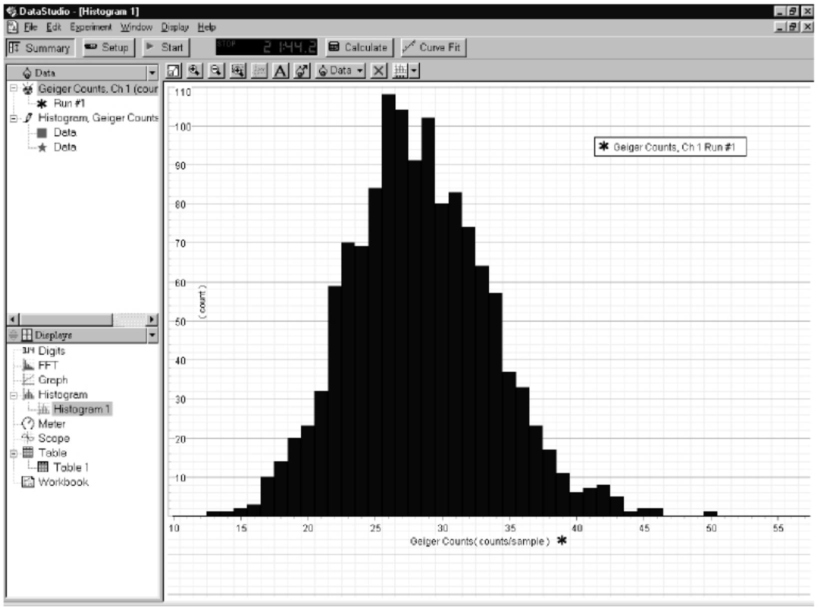


Figure 1: Data Studio Histogram Screen Capture

5. After you have completed Part B, your graph should resemble the one above, although the mean count rate will be different.

6. The transferred data from Capstone into a file in Excel. The tabular data should have the bin numbers in the first column (N range for the frequency counts) and the number of counts (frequency of the bin range) in the second column. Use Column C to calculate the formula (see Equation 1 below) for a Gaussian curve as a function of maximum probability P_{max}, center bin N_{ave}, and the standard deviation σ. These parameters should be placed in fixed cells so these values can be easily adjusted to match the function to the data. To calculate P_{max}, N_{ave}, and σ setup constant bin ranges as reviewed by your instructor and use Excel build-in functions to calculate these values. The built-in functions are as follows: for P_{max} '=max(highlight column of N), for N_{ave} '=average(highlight column of N), and σ '=stdev(highlight column of N)

$$P = P_{\max} \exp\left[-(N - N_{ave})^2 \Big/ 2\sigma^2 \right] \quad \textbf{(1)}$$

7. Create a graph of both your Capstone data and the predictive data from your calculated Gaussian Equation. Your group may need to adjust the parameters P_{max}, N_{ave}, and σ to match the Gaussian function to the data graphed. Adjust values until the Gaussion curve matches visually (of course as well as possible).

8. Compare the standard deviation calculated with the theory ($\sigma = N_{ave}^{1/2}$) for this type of statistical decay.

9. Using the histogram data, calculate the percent of counts that fall within 1σ, 2σ, and 3σ. Compare with expectations from the "Measurement Uncertainties" document located in the Resources Tab in Blackboard.

Part B: Exponential Decay

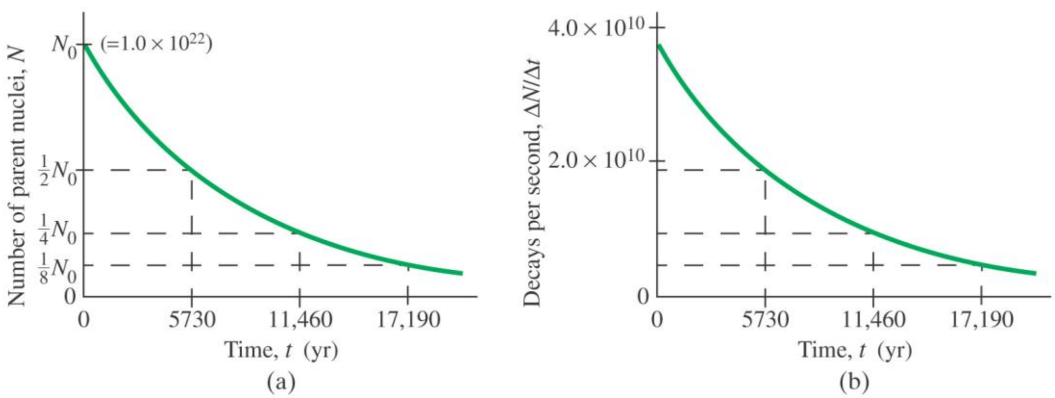
Radioactive decay is an exponential decay which is commonly seen in nature. The equation governing this decay depends upon the following variables.

- N_0 is the initial number of nuclei
- N is number of nuclei at a later time
- ΔN is number of decays in time Δt
- λ is called the decay constant

$$N = N_0 e^{-\lambda t} \qquad (2)$$

Activity defined as the number of decays per time ($\Delta N/\Delta t$) also decreases exponentially and thus the equation is similar to equation (2).

$$\frac{\Delta N}{\Delta t} = \left(\frac{\Delta N}{\Delta t}\right)_0 e^{-\lambda t} \qquad (3)$$



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The half-life $T_{1/2}$ is defined as the length of time needed for the values N_o or $(\Delta N/\Delta t)_o$ to be reduced to ½ of the original values.

$$T_{1/2} = \frac{0.693}{\lambda} \qquad (4)$$

Exponential decay will always occur when the number of decays over a period of time is proportional to the number of un-decayed nuclei (N). Given $-\lambda$, the probability of a decay, equation (5) demonstrates this proportionality.

$$\frac{\Delta N}{\Delta t} = -\lambda N \qquad (5)$$

Part B Procedure.

In order to test equations 2 through 5 on the previous page we will start with Eqn 5, which says that the number of decays per time period is proportional to N. Let's assume that each nucleus, in a sufficiently large collection of nuclei, has a 10% probability of decaying in 1.0 second. Using equation (5) we have

$$\frac{\Delta N}{1 second} = -\left(\frac{1}{s}\right) N$$

where the negative sign indicates that N is decreasing.

We could simulate this process using special dice with 10 sides. We could start by throwing about 10,000 dice. Each one of them would represent a nucleus. All those that show a 1 would have "decayed" and they would be removed from our collection. We would expect that the number removed $\Delta N \sim 1000$ (since probability of rolling a 1 is 10% for a 10-sided die) and thus the new $N \sim 9000$ for the 2^{nd} second. Each throw has a $\Delta t = 1.0$ second. We could then develop graphs of N vs. t and $(\Delta N/\Delta t)$ vs t. Finally, both graphs could be fitted with the proper trendline and demonstrate the exponential nature of the decays.

Clearly we could not do this with actual 10-sided dice, but the process is fairly easy to simulate in Excel using a random number generator. Please load the file named 'Radioactivity.xls' located on Blackboard and throw the 10,000 dice by hitting the THROW button. Graphs are already pre-generated in the file – have your group change the number of repetition of the throws and examine the results.

Your group should comment on the fit of the data displayed. Your instructor may ask you specific questions to answer in your group's report.