In the microscopic world chance plays a fundamental role. Some nuclei, the cores of atoms, spontaneously change into other nuclei with the accompanying emission of radiation. Nuclei are incredible objects. There is no way of predicting when a particular nucleus will undergo this decay. The best quantum mechanics can do is to predict the probability that decay will occur. Different species of nuclei have different characteristic half-lives. This is the time one must wait, on the average, before half of a collection of them has decayed. Half-lives vary over an enormous range, from a fraction of a second to millions of years. Since decays are chance occurrences, it is not the case that after one half-life exactly half of the nuclei will not have decayed. The number remaining fluctuates around the average. With sufficiently large numbers of nuclei it is possible to describe the process in terms of exponential relations.

The radioactive decay rates used as data in this laboratory were actually calculated using the following probability rule: The probability that any nucleus will decay in the time $\Delta t$ is $k\Delta t$, where $k$ is a constant characteristic of the nucleus and of the particular decay. Given this number a random number was selected in the range between 0 and 1. If the random number was less than $k\Delta t$, the nucleus was assumed to decay. The result is that if this process is carried out for every one of the $N$ nuclei in the sample, then the average number $\Delta N$ that decay in the time $\Delta t$ is $k\Delta t$.

It can also be shown that the rate of decay $R$ obeys an exponential relationship:

$$ R = R_0 \exp(-kt) $$

where $R_0$ is the rate of decay (i.e., the number of decays per unit time) at $t = 0$. The constant $k$ is related to the half-life $T$ in the following way:

$$ T = \frac{0.693}{k} $$

In the first activity today you will measure decay rates of a radioactive material with the aid of a Geiger counter. In activity 2 you will be given a table of decay rates and asked to determine the half-live of the radioactive material.

**Activity 1**

A Geiger tube and a counting circuit are to be used in this activity. The passage of radiation from the disintegrating material through the Geiger tube produces electrical pulses in the counting circuit. The circuit is designed to count these pulses, hence to count the particles or rays detected in the tube. The counting rate is, therefore, proportional to the rate of decay of the material. Since the rate of decay is proportional to the amount of material present at any given time, the counting rate is a measure of the amount of material remaining. Thus, data can be obtained for half-life determination.

Obtaining meaningful data is complicated by two effects, background radiation and the statistical nature of the decay process. Background radiation, typically 10 to 30 counts per minute, comes principally from cosmic radiation, with possibly some much smaller contribution from traces of radioactive isotopes in construction materials.
Your first step is to determine an average background count. Do this by counting for 10 different 60-second intervals. (If your counter can be set for 100 seconds but not for 60 seconds, use intervals of 100 seconds.) The average of these counts will be used as a correction to the data obtained for the decaying material.

The gathering of data on background probably will reveal the second complicating effect, the variation of counting rate from one interval to the next. Even for a rapidly decaying material, where the general trend in counting rate is downward, it is not unusual for the number of counts in a given interval to be larger than the number in the preceding interval.

These complicating effects can be minimized by

1. using large counting rates, so that background radiation is relatively insignificant, and
2. gathering enough data to smooth out statistical variations.

**Activity 2**

After you have determined an average background count, locate the file on your computer desktop entitled "decaydata". Open this file and copy the data into Excel. The first column shows minutes elapsed, and the second gives the number of decays which have occurred in each subsequent minute.

Subtract the average background (rounded to the nearest whole number) from the count obtained for each interval. Plot corrected counting rate versus time elapsed since the beginning of the first count. Estimate the half-life of the specimen from this graph.

Estimated half-life: __________________________

Plot the natural logarithm of the corrected counting rate versus time using either Excel or Graphical Analysis. Perform a least-squares analysis of this graph. Print a copy of this graph and attach it to these instructions. What is the value of $k$ according to the least-squares fit to your data?

$k = ______________________$

Calculate the half-life from your value for $k$. Show your calculations. $T_{1/2} = ______________________$

**Homework Problem**

1. A geiger tube/counter system yielded a counting rate of 500 counts/min at 12 noon for a certain radioactive sample. At 2:00 PM the same system yielded a counting rate of 300 counts/min. Find the half-life of the sample. Show your calculations.