Lab 2  Preparation Questions - Tear off this page and turn in at the beginning of Lab

Name

Section Day

Date

RADIOACTIVE DECAY: Relationships between parent and daughter nuclides

\[ N_0 = \text{initial number of radioactive parent atoms} \]
\[ N = \text{number of radioactive parent atoms at time of measurement} \]
\[ D_0 = \text{initial number of daughter atoms} \]
\[ D^* = \text{number of daughter atoms produced} \]

\[ \text{Eq1)} \quad N_0 = N(e^{\lambda t}) \quad \text{rearrange this equation to solve for } N \]

\[ \text{Eq2)} \quad D^* = N_0 - N \quad \text{manipulate this equation to solve for } D^* \text{ in terms of } N_0 \]

\[ \text{Eq3)} \quad D_{\text{total}} = D_0 + D^* \quad \text{substitute for } D^* \text{ in terms of } N \]
Natural Radioactivity

Natural radioactivity provides the most basic underpinning of our understanding of the timing of geologic events. Basically, everything we know about absolute dating of rocks, fluid residence times, and the timing of planetary differentiation is derived from our understanding of natural radioactivity. The singular beauty of natural radioactivity is that it is (believe it or not) a really simple phenomenon—relying on precisely the same formalism as your bank uses to accrue (or subtract) interest from your bank account/mortgage, or that biologists use to calculate growth of populations. The whole systematics of natural radioactivity depend on manipulating a single equation: \( N = N_0 e^{-\lambda t} \); here, \( N \) is the number of atoms of the radioactive element, \( N_0 \) is its initial concentration in the rock, \( t \) is age and \( \lambda \) is the decay constant, which can be shown to equal \((\ln 2)/(the \ half-life \ of \ the \ radioactive \ nuclide)\). These exercises are designed to help you play with this equation, and get a sense for the ubiquity and wonder of natural radiation…

The Cs/Ba radioactive isotope system (25 points)

In this experiment, you will record the decay curve of \(^{137}m\text{Ba}\), a meta-stable product of radioactive decay from \(^{137}\text{Cs}\). The half-life of the \(^{137}\text{Cs}/^{137}m\text{Ba}\) is approximately 30 years, but the half-life of \(^{137}m\text{Ba}/^{137}\text{Ba}\) is very short so there are no dangers of radioactive waste (whew!)

Before you start this experiment, you should practice using the geiger counter. Make sure you know how to start the counts, reset, etc. Next, make a data table to record your observations. You are going to make a graph of radioactive decay. What will be on your x- and y-axis? What sort of measurements will you be taking?

Once you get these logistical details figured out, your TA will squirt some solution containing \(^{137}m\text{Ba}\) on a cotton ball placed in a container. Record the gamma rays emitted from the radioactive solution. In order to make robust graphs, we want you to collaborate with your classmates. Either write your observations on the board or on an overhead sheet so others can compile your data into their results.

Next week, you will turn in a computer generated (excel, or some other graphing program) radioactive decay graph, an exponential equation (fit to this curve), and a half-life (calculated from your equation).
Radioactive Rocks! (25 points)

It is not widely appreciated how common natural radioactivity is. This portion of the laboratory is designed to provide you with both a sense for the abundance of uranium in two markedly different igneous rocks, and for the idea that even very slow rates of radiogenic decay produce measurable effects on a very short time span. The two rocks you're examining are a common granite from the Eastern Sierra and a basalt from the Columbia River deposits in Washington state. Neither is anomalous in their radiogenic element content in any way (in fact, the CR basalt is probably a little low in its uranium content relative to most basalts).

Assume that the primary source of radioactivity you will record in these rocks is produced by the decay of uranium -- 99.27% of almost all naturally occurring uranium is $^{238}\text{U}$, with 0.72% being $^{235}\text{U}$. $^{238}\text{U}$ has a half-life of about $4.47 \times 10^9$ years, while $^{235}\text{U}$ has a half-life of $7.04 \times 10^8$ years.

The total decay reaction of $^{238}\text{U}$ to its stable daughter, $^{206}\text{Pb}$ (Pb is lead), involves the production of 8 $^4\text{He}$ atoms, 6 beta particles (energetic electrons) and 8 gamma-ray photons. On its way to lead, it decays through eleven other separate elements and eighteen isotopes with half-lives of all the steps summing to $4.47 \times 10^9$ years. Among the side products are two isotopes of radon, which produces a significant environmental problem in large portions of the country.

The detector you'll use is a gamma ray detector, which detects high-energy photons emitted during some types of radioactive decay (for example, about 90% of the radioactive decay of $^{40}\text{K}$ (potassium) does not involve emission of a gamma ray). These are generally in the x-ray region of the spectrum (in fact, that's what this detector is usually used for -- an x-ray detector). There are other natural sources of gamma-rays, of which the principal one is cosmic rays. Thus, when you make a measurement on a rock or a background measurement, hold the detector pointed to the side -- not up. There's also going to be some intrinsic noise from the detector, too.

Step 1) Take a background measurement. Count the number of counts emitted by the clicker over a 1-minute span with no sample in front of it. Record your measurement.

Step 2) Record the number of counts from each rock for an amount of time (i.e. 50 seconds or 2-minutes). Hold the rock in front of the detector's window (if you can't determine where the window is located, ask your TA). Please don't touch the rock to the surface of the detector's window.

Step 3) Subtract the number of background counts from the rock counts. Using the half-life above and assuming all the decay is produced by decay of $^{238}\text{U}$, what percentage of uranium by weight is each rock? Please report your answer with 3 significant figures. Also, additional information needed => each atom of uranium weighs 238 g/mole, and each mole has $6.022 \times 10^{23}$ atoms (a handy little number named after a 19th century scientist, Avogadro). You will have to measure the masses of your rock samples with the triple-beam balance. HINT: Keep in mind, gamma-rays can go in any direction, not just into the detector (including towards the ceiling, into your hand, etc.). If they go elsewhere, you won't record them. My advice is to estimate this geometric effect (but give the basis for your estimate). Also, remember how many gamma rays are generated during the decay. Speculate as to why you get (or didn't get) different answers for the two rocks: what could have been (or wasn't) different about their formation?
A brief aside on statistics: If we were really doing this right, we would count each rock and the background for 10,000 counts or more (any volunteers can stay after class). That number of counts typically reduces errors produced by the randomness of the decay process to less than 1%. After a minute of counting on the background and the rocks, your errors will be rather larger, but most (and possibly all) of you should get answers on the right side for one of the rocks on the first try; a few of you might have to recount one of the rocks (or, worse yet, count for longer!).

Oh, by the way... just for your information -- all plant tissue contains a small amount of $^{14}$C, with a half life of about 5730 years. Plant tissue typically has about 15.3 disintegrations/minute/gram of carbon (yes, even organic vegetables have it). So, your average salad, piece of fruit or bag of sprouts (4 ounces = about 100 grams, with probably 50 or so of it being carbon) produces about 750 radioactive decays per minute that, needless to say, you generally don't just hold in your hand. In case you're interested, the specific decay process is $^{14}$C -> $^{14}$N + a positron (a subatomic particle like an electron, but with a positive charge) + a neutrino (so no gamma rays, but plenty of energy) -- Bon appetit!

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**PROBLEM 1** (10 points)

What would be the age of a zircon crystal if it contains 16.7 million atoms of $^{238}$U and 8.2 million atoms of $^{206}$Pb? The crystal had an initial quantity of 6.5 million atoms of $^{206}$Pb. Assume the system is closed and that $T_{1/2}$ is $4.47 \times 10^9$ years.

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**PROBLEM 2** (10 points)

If a host rock initially contains 8.0 million atoms of $^{40}$K, calculate how many atoms of the daughter, $^{40}$Ar, would be produced in:

(a) 33.7 million years  
(b) 65.5 million years  
(c) 199.6 million years

Again, assume a closed system and $T_{1/2}$ is $1.25 \times 10^9$ years.
**PROBLEM 3** (10 points)

How many atoms of $^{238}$U decay per second in a 5.30-gram sample of the pure isotope ($T_{1/2}$ is $4.47 \times 10^9$ years)?

**PROBLEM 4** (20 points)

Here's a table for minerals from the achondritic meteorite, Juvinas (data is from Allegre et al., 1975). An achondritic meteorite comes from a differentiated parent object (a small planetesimal for example).

<table>
<thead>
<tr>
<th>MINERAL</th>
<th>$^{87}$Sr/$^{86}$Sr</th>
<th>$^{87}$Rb/$^{86}$Sr</th>
</tr>
</thead>
<tbody>
<tr>
<td>glass</td>
<td>0.7049</td>
<td>0.0881</td>
</tr>
<tr>
<td>tridymite</td>
<td>0.7008</td>
<td>0.0242</td>
</tr>
<tr>
<td>quartz</td>
<td>0.6996</td>
<td>0.0080</td>
</tr>
<tr>
<td>pyroxene</td>
<td>0.6994</td>
<td>0.0032</td>
</tr>
<tr>
<td>plagioclase</td>
<td>0.6993</td>
<td>0.0022</td>
</tr>
</tbody>
</table>

Calculate the age of the meteorite using the Rb/Sr method. Make an appropriate plot and show all your work. Indicate what the value of $^{87}$Sr/$^{86}$Sr was at $t = 0$. Discuss briefly why the $^{87}$Rb/$^{86}$Sr values are different for the various minerals in the meteorite. The half life of $^{87}$Rb, which decays into $^{87}$Sr, is $4.88 \times 10^{10}$ years.