Young Physicists Program: May 2011

Lab 8: Radiation and Nuclear Physics- Do Not Lick

Laboratory: Types of radiation, sources of radiation, and shielding

Introduction

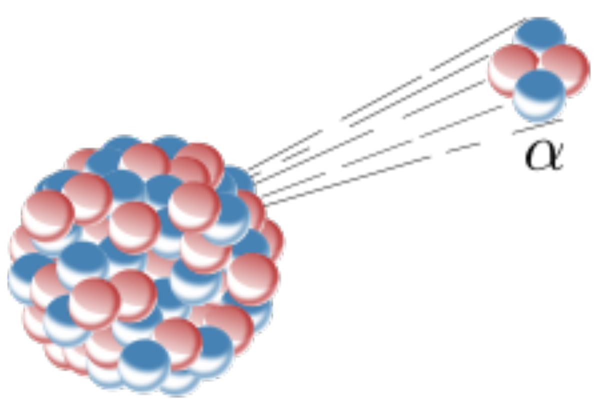
The purpose of this lab is to study the various types of radiation, their role in everyday and exceptional phenomena, and to also understand some of the principles underlying nuclear physics.

Lab

-*Types of Radiation*

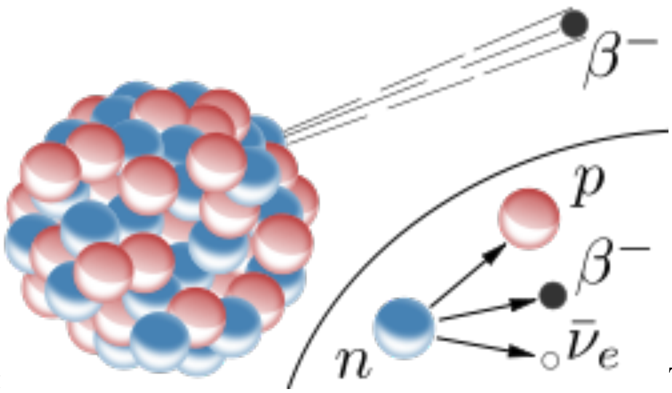
First, discuss the three types of radiation. What type of particle is emitted in each process? Which is the most harmful? Can all three types cause an element to decay to another element?

Here's a guide:

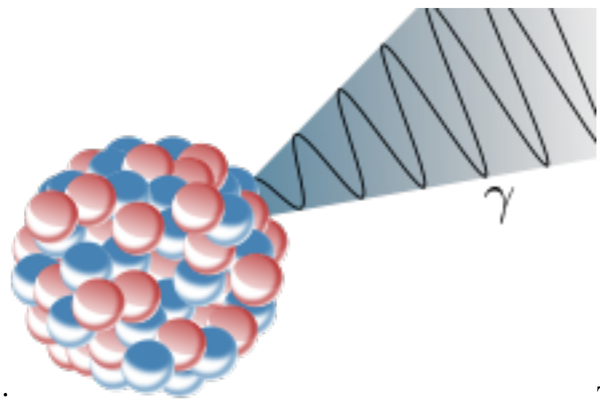


Alpha: Typical energy: ~5 MeV

(110 TJ/kg!)

Beta: 

TE: 0-10 MeV

Gamma: 

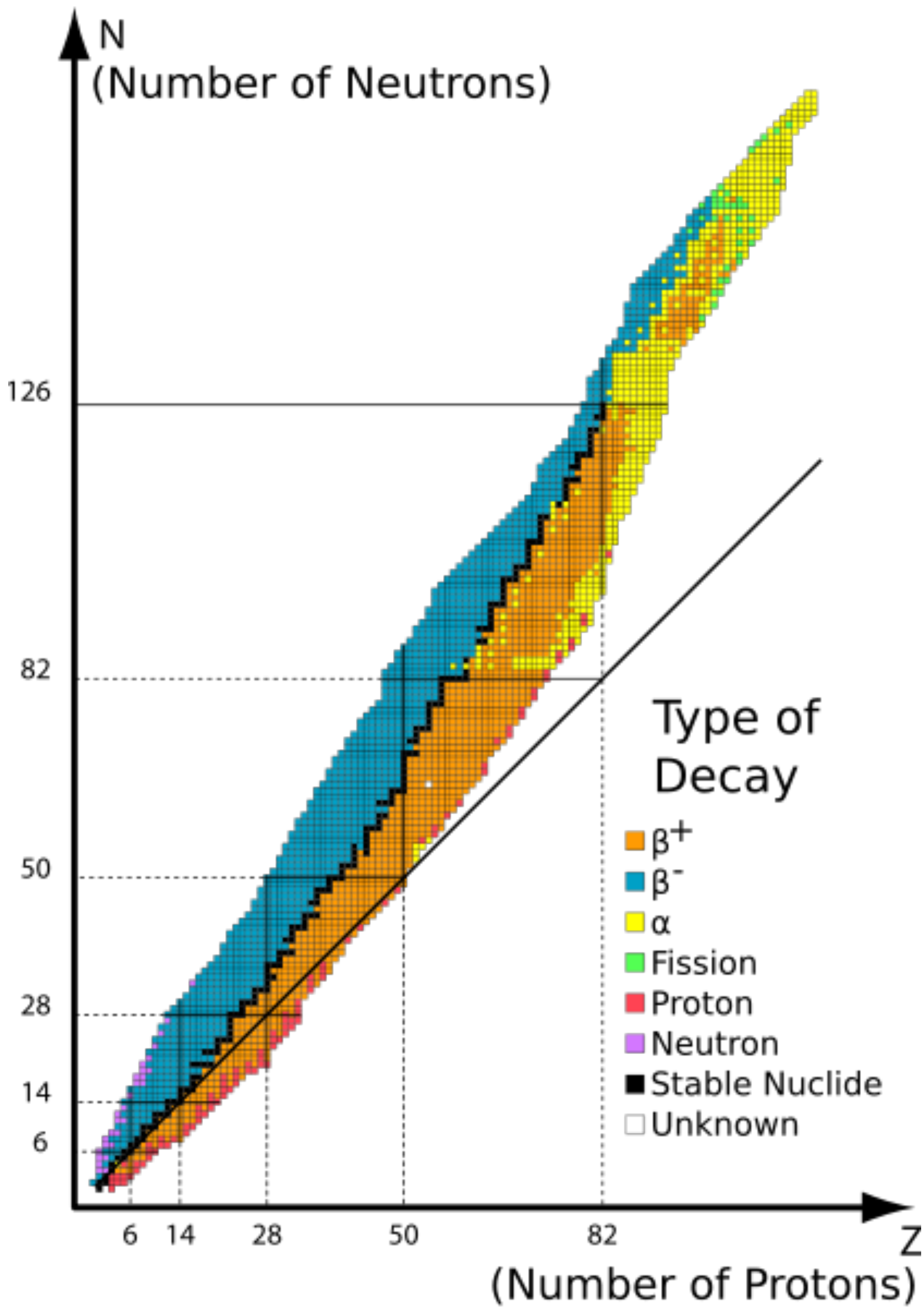
TE: .1 MeV - 10 MeV

You will figure out what can protect you from these sources later in the lab. Finally, look at the chart on the next page. What is the most common type of decay in nature? Figure out what the chart means.

-Half life

We can now talk about half life. The **half life** of an element (that is unstable!) is defined as the time for an element to have half of its quantity decay to other things. For example, if you had 1 kg of *pure* Cobalt-60 (can be a very dangerous element), which has a half life of about 5.3 years. 5.3 years after you got the cobalt, only .5 kg of the original amount would be Co-60, the rest having gone to other elements (in this case, through beta decay).

When and why a specific atom in an element decays is probabilistic (i.e. random) and determined by quantum mechanics. We can simulate this randomness here by shaking up a cup of M&Ms and spreading them out on the table. Each piece has a 50% chance of



coming out with "M" on top. Now, think of the cup of candy as an element (say, Cobalt-60) with lots of atoms in it (the M&Ms). Shake up the cup and spread the M&Ms out. If any piece has "M" face up, this atom has decayed (by which processes?)- simulate this by eating the candy. Put the candy back in the cup and do this process a few times. How many M&Ms are left at the end, relative to how many you started with? Does this match with what you expect? Does the shaking of the cup represent a specific amount of time? What is that time? Was the candy yummy? If so, then so are the by-products of radioactive decays.

-Decay Chains

Decay chains are what really happens when you have elements with different half-lives decaying into each other. Show it this way:

1. You and your 19 closest friends have been turned radioactive. You will start to decay towards something more stable (teenagers→20-somethings→???). To represent this each turn you will roll 2 dice.
2. Initially you are element X, which has a long decay rate, and as such you will only decay on a roll of 12.
3. Once you decay, you are now element Y. Element Y is a feisty one and you will decay into element Z if you roll an 8 or more.
4. Element Z is still not stable and you will decay a final time on a roll of 10 or more.
5. Each time you decay, indicate that you have decayed so the grad students can take readings. (This means making a plot of decay events vs # rolls, grad students).

What do the conditions for decay mean in real elements? Without doing any actual calculations, take that the half life of Uranium-235 is 704 Byrs (this is the same Uranium used in atomic bombs! Why the long half life?) and that the half life of

-Measuring radiation

Now, finally, let's look at some real radioactive materials. We are going to use a **geiger counter** to count radiation from your ambient surroundings and also from specified sources of various types of radiation. How does a geiger counter work? Does the noise mean anything? Discuss with your grad student.

Before doing any actual measurements, note the following units for radiation measurement (there are a lot, watch out!):

1 Curie = 37 billion Becquerel = 37 billion disintegrations/second

1 Sievert = 100 rem = equivalent absorbed dose of radiation = 1 J/kg

1 rad = .01 Grays = .01 J absorbed /kg

1 CPM = 1 Count per minute (of any ionizing radiation)

Great, cool, mellifluous. Let's measure the radioactivity of some household materials, and then some more significant sources. Set your Geiger counters to "fast" count (the "F" with the rabbit), the x0.1 setting on the knob, and the count clicks audible.

1. Count the number of audible clicks you hear over one minute with the Geiger counter just sitting on the table, away from the banana (STAY AWAY FROM THE BANANA) and the KCl sample. Write this down. Where is this radiation coming from?

2. Now do the same with the Geiger counter next to the **banana**.

3. Do the same with the Geiger counter on top of the KCl sample. KCl contains lots of potassium, K, and in particular naturally occurring potassium has 0.012% of it as K-40, which is an isotope of potassium that decays via beta decay with a half-life of ~1.2 Byr. It is naturally in your body Bananas also contain lots of potassium. Does the banana or the KCl contain more K-40? How do you know?

4. Repeat this 3 times, and record the number of counts for each step.

5. [*A short, boring, but important detour in statistics*] Now, make a table of the number of counts for each of the above radiation sources. Calculate the average number of counts for each source. Now calculate the standard deviation of each set of counts. This will be very boring, so make it more amusing by, say, calculating the standard deviation abacus-style, with your leftover M&Ms.

a. Also calculate the sqrt(N), the number of counts, for each trial above. How does this compare to the standard deviation you calculated for each set of counts?

b. You are asked this because radiation/decay is a random process. In particular, the number of counts per second (or counts per minute!) you record from your counter follows a *Poisson distribution*, and it has a standard deviation of sqrt(N), where N is the number of measurements (i.e counts) you have made.

-*Other radioactive sources and shielding*

A graduate student at the center of the room will guide you through how to determine the type of radioactive emitter by looking at radiation counts after various shields (e.g.

cardboard, aluminum, lead) are placed between the source and your Geiger counter. Please do as that student says when studying these alpha, beta, and gamma sources. You may find out that some interesting emitters of radiation, like a strong alpha emitter, exist in common household items you may have!

Demos

-*Take a random hike!*

Many physical processes are described by a "**random walk**." You will simulate this by trying to escape from a tessellation of square or hexagons. If you are 5 blocks away from escaping to outside the tessellation, how many steps do you need, on average, to get out? What if you were 10 blocks from all escape points? Some nuclear reactions and even light trying to get out from the center of the sun are described by this idea.

-*Simulated nuclear chain reaction*

We want to simulate how a **nuclear chain reaction** forms. This involves the idea of a critical mass. We will demonstrate what a critical mass is, and how it depends on things like shape and density, by sending a human neutron into a collection of human uranium atoms, and seeing if we can sustain a chain reaction.