Lesson 44: Half Life

The **half life** of an element is the time it will take ***half*** of the parent atoms to transmutate into something else (through alpha or beta decays, or another process).

- This amount of time varies from just 10^{-22}s to 10^{28}s … that's 10^{21} years!
- The total number of atoms in a sample stays the same, it's just that some of the atoms have changed to different elements.

Half life is totally based on probabilites and statistics, so anything that we say is just a best guess based on previous experience.

Example 1: The half life of $^{14}_{6}C$ is 5730 years. **Explain** what you would expect to happen over a long period of time.

Imagine a sample of carbon that originally had 100 of these carbon-14 atoms. In reality we would need the sample to have many more atoms, since statistics are really only reliable for large numbers.

During the first few hundred years or so we would notice that some of the carbon-14 atoms have transmutated into some other element. In fact, a lot of them have changed. Since we started with a lot of the carbon-14 atoms, there is the greatest chance of seeing quite a few change. It would be like throwing 100 quarters into the air; since there are so many, you've got a really good chance of seeing a 50-50 split between heads and tails when they hit the ground.

By the time 5730 years have passed, we would expect to only have 50 carbon-14 atoms remaining. Remember, the half life is the time it takes for half of them to change. There are still the same total number of atoms, just not as many carbon-14 as we started with.

Some people think that if we wait another 5730 years, all of the carbon-14 will be gone... nope! Remember, half life is the time it takes for half the atoms to decay. So, after the next 5730 years we would expect 25 carbon-14 to be left; that's half of the 50 that we had after the first half life.

And so on, and so on... Eventually, after about six or seven half lives have passed, the number of carbon-14 atoms becomes so small that probabilities fall apart and you basically have the last few atoms decay whenever.

Start	***1 Half Life***	***2 Half Lives***	***3 Half Lives***	***4 Half Lives***	***5 Half Lives***
0 Years Passed	**5730 years**	**11 460 years**	**17 190 years**	**22 920 years**	**28 650 years**
100 atoms	50 atoms	25 atoms	12 or 13 atoms	6 or 7 atoms	3 or 4 atoms
This is the original amount. No decays yet.	Since one half life has passed, we have half the atoms we started with.	Remember, half of the amount we had, not what we started with.	Half of the previous amount. We can't be exact, since we are rounding off a number based on statistics.	Statistics really start to break down when we have this few atoms.	You have a chance of throwing 4 quarters in the air and they all land as tails. Same thing here... all of these might decay in one half life.

Activity

As a sample of something is decaying and going through half lives, we can measure the **activity** of the sample.

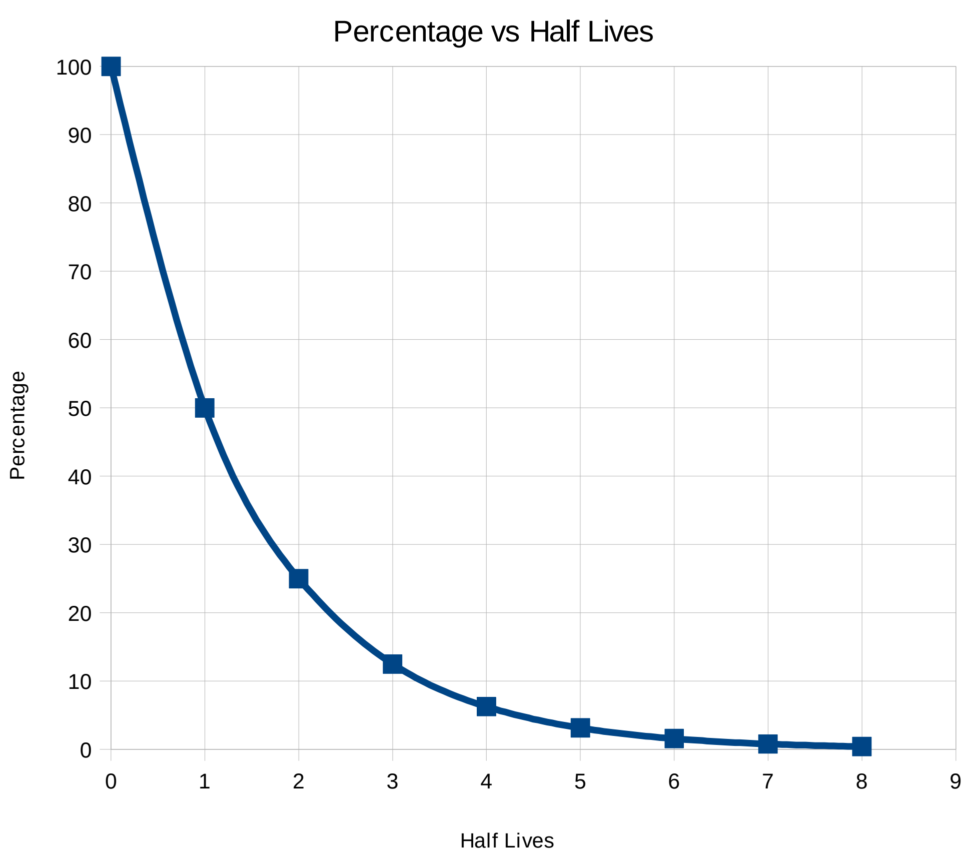
- Activity measures the number of nuclei that decay per second (sometimes also called the decay rate).
  - It is usually measured in Becquerels (Bq), which is equal to decays/second.
- The familiar clicking of a Geiger counter in movies is measuring the activity of the sample.
- As time passes, the number of nuclei available to decay decreases, so the activity of the sample drops.

Illustration 1: A Geiger counter.

Consider **Example 1** from above...

- At first there were 100 nuclei that had the *possibility* to decay. There was a good chance that out of that 100 we would see some decay. Using a device like a Geiger counter, maybe we measure its activity at something like 72Bq (*for example*).
- After 5730 years, there are only 50 nuclei left. The number of decays per second (activity) will also drop to half the original since there are only half as many chances to have decay happen. Following the example activity we started with, we would expect to see an activity of 36Bq.
- After another 5730 years, the activity will have dropped by half again to about 18Bq.

Whether you are looking at number of atoms left, or activity of the sample, the percentage remaining is an exponential curve.



There's a formula on your data sheet for taking care of these types of questions.

- The amount can be either atoms, or mass (any units), or activity. Just make sure you keep the units the same.

$$N = N_o\left(\frac{1}{2}\right)^n$$

N = amount after time has passed
N_o = original amount
n = number of half lives

Example 2: Marie Curie had a 765g sample of polonium-210 (half life = 138d) in a box. After 3.8 years of refining radium, she goes to the box to get her polonium. **Determine** how much polonium-210 is in the box.

First, we need to get our units for time the same, so figure out how many days there are in 3.8 years.

$$3.8\,\cancel{a}\left(365\frac{d}{\cancel{a}}\right) = 1387\,d$$

Now we can figure out how many half lives have passed (the "n" value in the formula).

$$n = \frac{1387\,d}{138\,d/half\ life} = 10.0507246377\ half\ lives$$

Now we figure out how much polonium-210 is remaining.

$$N = N_o\left(\frac{1}{2}\right)^n$$
$$N = 765(0.5)^{10}$$
$$N = 0.7212599892 = 0.72\,g$$

We could argue whether or not the answer has two or three sig digs; I put it as two since the time (in years) that passed is two sig digs.
By the time Madame Curie gets back to her box, she'll only find that 0.72g of polonium-210 is remaining. There is still a total of 765g of stuff in the box, but only 0.72g of it is polonium-210. The other 764.28g of stuff would be other elements that the polonium-210 decayed into.

Example 3: You have 75.0 g of lead-212. If it has a half life of 10.6h, determine how long it will take until only 9.30 g remains.

This question is tougher than the previous example. If you write out the formula, here's what you get…

$$N = N_o\left(\frac{1}{2}\right)^n$$
$$9.3 = 75\left(\frac{1}{2}\right)^n$$
$$9.3 = 75(0.5)^n$$

Method 1: Logs
Now, if you're good with logarithms in math, you can go ahead and solve it.

$\frac{9.3}{75} = 0.5^n$ Simplify your expression a bit.

$0.124 = 0.5^n$

$\log_{0.5} 0.124 = 3.01158797$ Solve the logarithm to find out how many half lives.

$3.01158797 \, x \, 10.6 \, h = 31.9 \, h$ Multiply half lives by time in one half life.

Method 2: Guess and Check
But in Physics 30 you are not required to use logs, so there is an easy way to estimate.

1. Type 75 into your calculator and divide by 2. You should get 37.5. So, after ***one*** half life you've got 37.5g left.
2. Divide 37.5 by 2 to get 18.75… so after ***two*** half lives you've got 18.75g.
3. Divide 18.75 by 2 to get 9.375. After ***three*** half lives have passed you've got 9.375g left. That's pretty close to the 9.30g in the question, so after just a little more than three half lives you should have 9.30g left over.

Take the half life of the material (10.6h) and multiply it by 3 half lives to get 31.8 hours! That's pretty close to our wonderful answer calculated above using logarithms.

Homework

p813 #2
p817 #5-8