Lab 12: Radiation 1

Physics 227L

Introduction

The activity (in decays per second) of some radioactive samples varies in time in a particularly simple way. If the activity *(R)* in decays per second of a sample is proportional to the amount of radioactive material (R $\propto$ N, where N is the number of radioactive nuclei), then the activity must decrease in time exponentially:

$$R(t) = R_0 e^{-\lambda t}$$

In this equation λ is the decay constant, commonly measured in s^{-1} or min^{-1}. R_0 is the activity at t = 0. The SI unit of activity is the Becquerel (Bq), defined as one decay per second.

You will use a source called an isogenerator to produce a sample of radioactive barium. The isogenerator contains cesium-137, which decays to barium-137. The newly made barium nucleus is initially in a long-lived excited state, which eventually decays by emitting a gamma photon. The barium nucleus is then stable, and does not emit further radiation. Using a chemical separation process, the isogenerator allows you to remove a sample of barium from the cesium/barium mixture. Some of the barium you remove will still be in the excited state and will subsequently decay. It is the activity and lifetime of the excited barium you will measure.

While the decay constant λ is a measure of how rapidly a sample of radioactive nuclei will decay, the half-life of a radioactive species is also used to indicate the rate at which a sample will decay. A half-life is the time it takes for half of a sample to decay. That is equivalent to the time it takes for the activity to drop by one-half. Note that the half-life (often written as $t_{1/2}$) is not the same as the decay constant λ, but they can be determined from one another by solving the above equation with $R(t) = \frac{R_0}{2}$. This gives

$$t_{1/2} = \frac{\ln 2}{\lambda}$$

Also, note that your detector will always pick up some background radiation from various sources in the environment. While this amount is very small, it will become the main source once all your sample has decayed away. Thus to get a good fit we have to adjust the first equation to

$$R(t) = R_0 e^{-\lambda t} + b \qquad (1)$$

As a final note, do not handle the radioactive material at all, your instructor will do everything, don't touch.

Experiment

For analysis purposes the general form of this equation can be written as

$$y = ae^{-ct} + b$$

Question 1:

Compare this equation to equation (1) above, what are a, b and c equal to?

Procedure

A.) Start by opening LoggerPro on your computer, either from the desktop or start menu, then go **File->open->Nuclear Radiation with Vernier"->"Lifetime.cmbl"**

B.) Go to the **Experiment** tab and open **data collection**, check to make sure the Length is set to 30 minutes, and the rate is set to 2/minute.

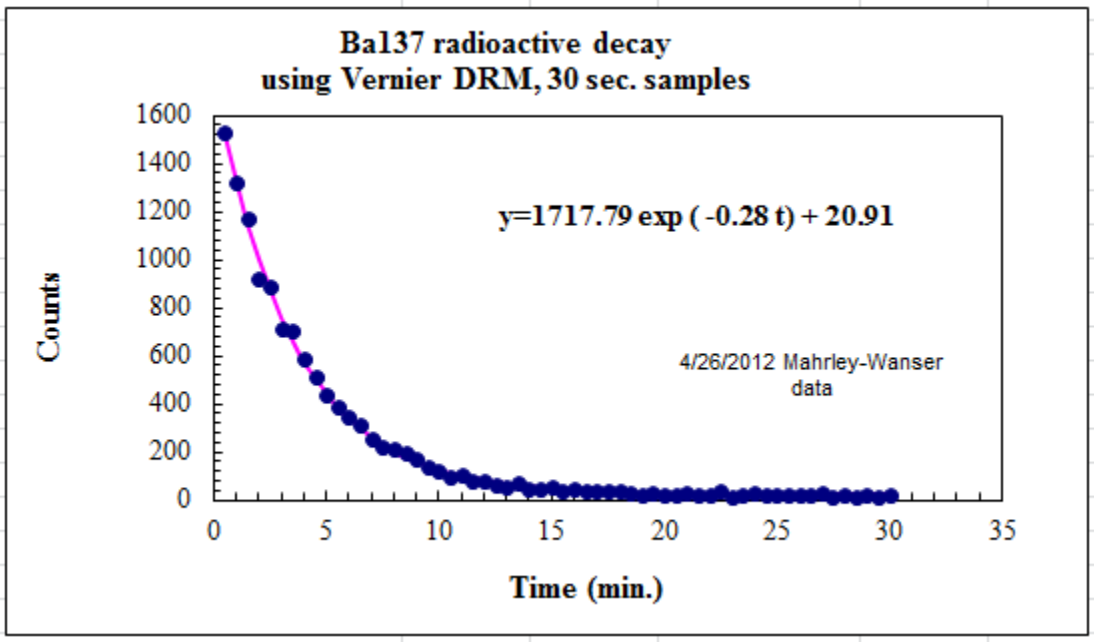
C.) As soon as the Ba-137 sample is prepared, hit collect, then wait for 30 minutes while it collects data. During this time, answer the two **PRELIMINARY QUESTIONS on the following page**.

D.) After data is collected, export it to a .csv file and copy the data over to your Ba-137 analysis from the excel lab at the beginning of the semester.

E.) Now use the solver to fit the equation to your data, you should have now solved for constants a, b, c. The guide for using the solver is attached at the end of the lab for the case that you've forgotten it or have lost your week 1 spreadsheet.

F.) You should now have two columns for N, one theoretical and one experimental, be sure that both are included as two series on your graph. The experimental set should be points, and the theoretical set should be a smoothed scatter.

G.) Manually write in the fit you've generated using a text box in excel, in the end it should look like the following, with your own data and titles of course.



H.) Print out your graph of data with the fit YOU GENERATED USING THE SOLVER included. and paste it into your notebook.

I.) Jump to the **Data Analysis** section now.

PRELIMINARY QUESTIONS

Question 2:

Consider a candy jar, initially filled with 1000 candies. You walk past it once each hour. Since you don't want anyone to notice that you're taking candy, each time you take 10% of the candies remaining in the jar. Sketch a graph of the number of candies for a few hours. *This is a simple metaphor for what's happening in radiation, though in the next lab you'll see it's a bit more complex.*

Question 3:

a) How would the graph change if instead of removing 10% of the candies, you removed 20%?
b) Sketch your new graph. *This represents a radioactive sample with a shorter half-life.*

Data Analysis

Question 4:

Inspect your graph. Is the decrease in count proportional to the amount of radioactive material remaining? Explain your answer

Question 5:

Compare your graph to the graphs you sketched in the Preliminary Questions. How are they different? How are they similar? Why are they similar?

Question 6:

From the fit parameters, determine the following **with their units**
Hint: (refer to question 1).

a) the decay constant λ
b) then the half-life $t_{1/2}$

Question 7:

a) Calculate a percent error between your half life and the accepted value of approximately 2.552 minutes for the half-life of the unstable barium-137.
b) What may have caused this error? Keep this in mind for the end of your report.

Question 8:

a) Use your fit equation to calculate what fraction of the initial activity of your barium sample would remain after 25.2 minutes.
b) Was it a good assumption that the counts in the last five minutes would be due entirely to non-barium sources? Explain your answer

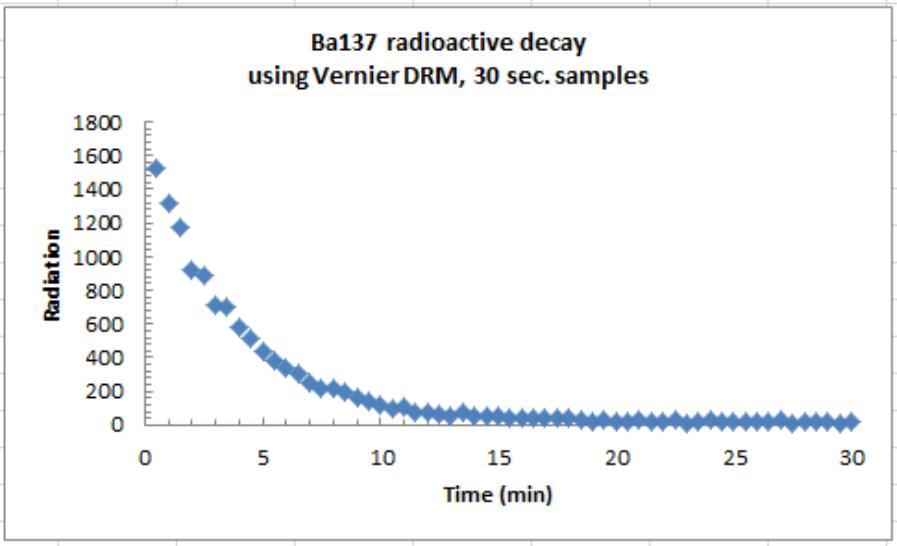
Using Excel solver to fit a curve

This section will guide you to generating your own fit line, aka trend line, when excel just can't quite do it.

As a guide, we'll generate a fit for an experimental data set from a lab toward the end of the semester on radiation, this data should be provided to you.

A.) The first thing we need to do is make a chart so we can see the data set, start by making a properly formatted graph as shown below

Data	
Time	Radiation
0.5	1531
1	1321
1.5	1170
2	924
2.5	885
3	709
3.5	706
4	586
4.5	512
5	435
5.5	387
6	342
6.5	310
7	251
7.5	223
8	216
8.5	194
9	168



B.) Now we need a theoretical fit, as you might guess the theoretical equation for above is a negative exponential, of the form

$$y = e^{-x}$$

Where y is the radiation, and x is time.

We can generalize this by adding some constants, like a slope and y intercept for a line we can add the following

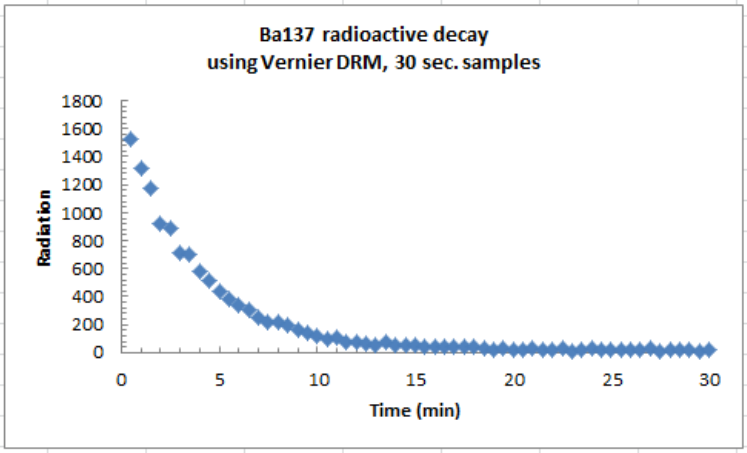
$$y = ae^{-cx} + b = Theoretical\ Radiation \quad (1)$$

We'll add this is a new column to our data set, where a, b and c are fixed values, so hard reference them from separate cells as shown below

See the formula box for the equation if you need help.

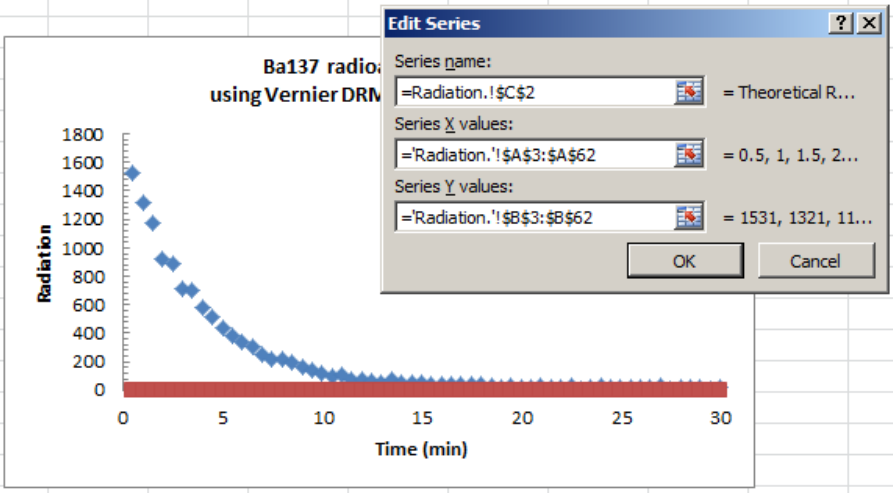
C3 =$E$4*EXP(-$G$4*A3)+$F$4

	A	B	C	D	E	F	G	H	I	J	K
1	Data										
2	Time	Radiation	Theoretical Radiation								
3	0.5	1531	1.60653066		a	b	c				
4	1	1321	1.367879441		1	1	1				
5	1.5	1170	1.22313016								
6	2	924	1.135335283								
7	2.5	885	1.082084999								
8	3	709	1.049787068								
9	3.5	706	1.030197383								
10	4	586	1.018315639								
11	4.5	512	1.011108997								
12	5	435	1.006737947								
13	5.5	387	1.004086771								
14	6	342	1.002478752								
15	6.5	310	1.001503439								
16	7	251	1.000911882								
17	7.5	223	1.000553084								
18	8	216	1.000335463								
19	8.5	194	1.000203468								
20	9	168	1.00012341								
21	9.5	140	1.000074852								



C.) Add this new set of radiation values as a second series on your graph by right clicking ->Select data-> Add, as shown

	A	B	C	D	E	F	G	H	I	J	K	L	M
3	0.5	1531	1.60653066		a	b	c						
4	1	1321	1.367879441		1	1	1						
5	1.5	1170	1.22313016										
6	2	924	1.135335283										
7	2.5	885	1.082084999										
8	3	709	1.049787068										
9	3.5	706	1.030197383										
10	4	586	1.018315639										
11	4.5	512	1.011108997										
12	5	435	1.006737947										
13	5.5	387	1.004086771										
14	6	342	1.002478752										
15	6.5	310	1.001503439										
16	7	251	1.000911882										
17	7.5	223	1.000553084										
18	8	216	1.000335463										
19	8.5	194	1.000203468										
20	9	168	1.00012341										
21	9.5	140	1.000074852										
22	10	123	1.0000454										



D.) This is your soon to be fit line, notice though that its currently not very good, this is because I've assumed a, b and c are all equal to 1, which isn't right. The next step is to find those values by using the excel solver

E.) Excel Solver is a minimization tool, it will minimize a single cell by changing some parameters, so first we need to give it something to minimize.

In this case, what we need to minimize is the distance between our experimental y values, the B column, and our theoretical y values, the C column. To calculate this distance we'll use the sum of squares, which can be done with the function

$$= SUMXMY2(Theoretical\ COLUMN, Experimental\ COLUMN)$$

Type this into a cell in excel as shown, reference the formula bar.

I4 =SUMXMY2(B3:B62,C3:C62)

	A	B	C	D	E	F	G	H	I	J	K
1	Data										
2	Time	Radiation	Theoretical Radiation								
3	0.5	1531	1.60653066		a	b	c		Sum of squares		
4	1	1321	1.367879441		1	1	1		9560648.27		
5	1.5	1170	1.22313016								
6	2	924	1.135335283								
7	2.5	885	1.082084999								
8	3	709	1.049787068								
9	3.5	706	1.030197383								
10	4	586	1.018315639								
11	4.5	512	1.011108997								
12	5	435	1.006737947								
13	5.5	387	1.004086771								
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16	7	251	1.000911882								
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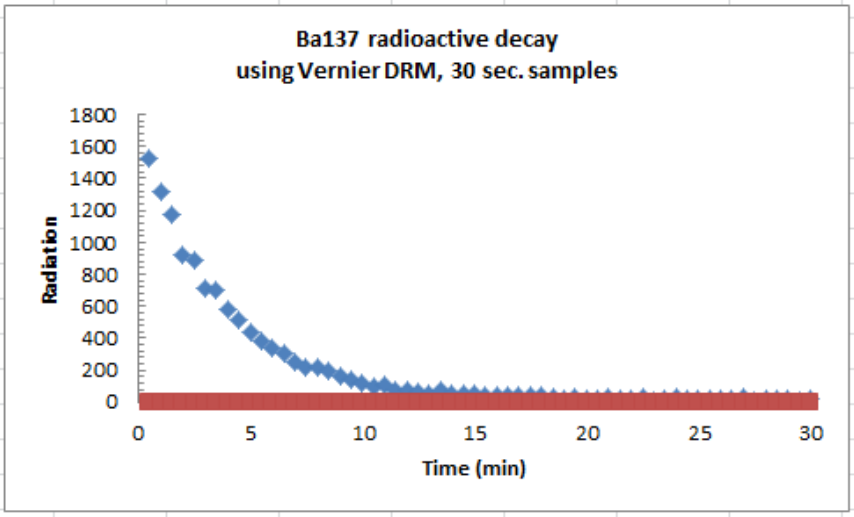
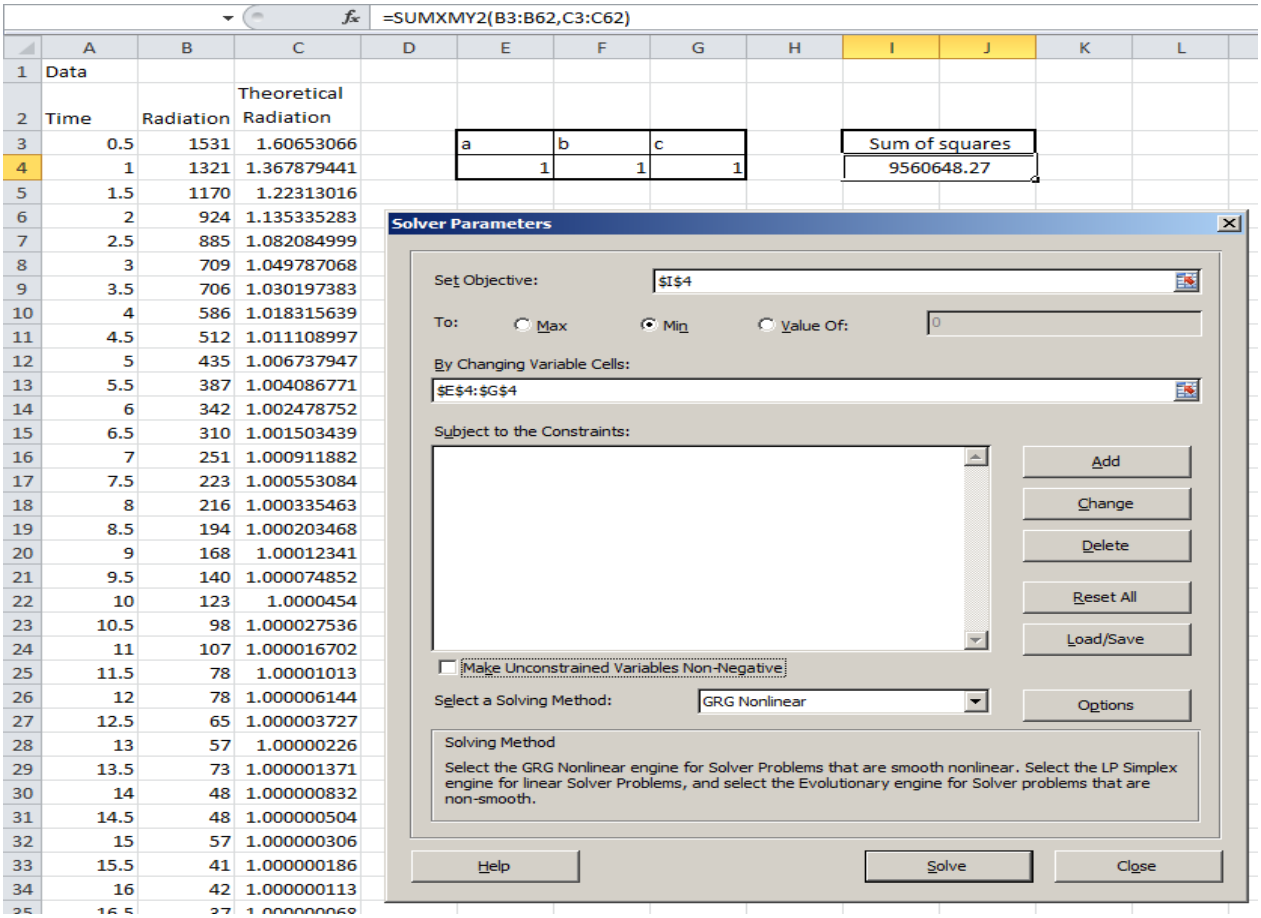
18	8	216	1.000335463								
19	8.5	194	1.000203468								
20	9	168	1.00012341								
21	9.5	140	1.000074852								



F.) This value is currently the sum of all the differences squared, so its huge, but now we can minimize it by running the solver which will change a, b and c. This will bring the red line as close to the blue line as possible.

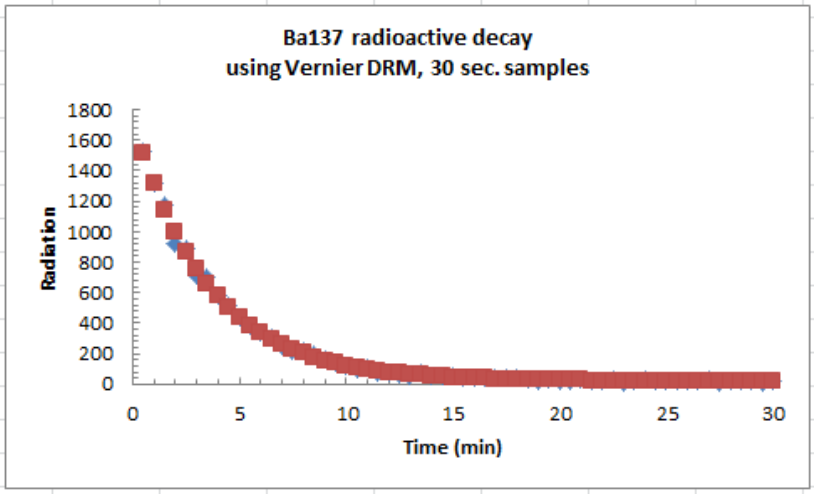
The solver is in the data tab on the far right, ask your instructor to help you find it. Reference the following page to run it.

Before and after shown below



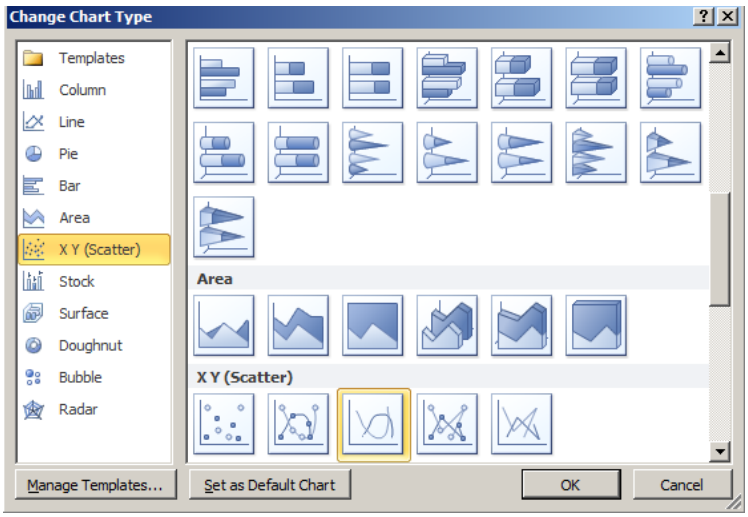
	A	B	C	D	E	F	G	H	I	J	K	L
1	Data											
2	Time	Radiation	Theoretical Radiation									
3	0.5	1531	1.60653066		a	b	c		Sum of squares			
4	1	1321	1.367879441		1	1	1		9560648.27			
5	1.5	1170	1.22313016									
6	2	924	1.135335283									
7	2.5	885	1.082084999									
8	3	709	1.049787068									
9	3.5	706	1.030197383									
10	4	586	1.018315639									
11	4.5	512	1.011108997									
12	5	435	1.006737947									
13	5.5	387	1.004086771									
14	6	342	1.002478752									
15	6.5	310	1.001503439									
16	7	251	1.000911882									
17	7.5	223	1.000553084									
18	8	216	1.000335463									
19	8.5	194	1.000203468									
20	9	168	1.00012341									
21	9.5	140	1.000074852									
22	10	123	1.0000454									
23	10.5	98	1.000027536									
24	11	107	1.000016702									
25	11.5	78	1.00001013									
26	12	78	1.000006144									
27	12.5	65	1.000003727									
28	13	57	1.00000226									
29	13.5	73	1.000001371									
30	14	48	1.000000832									
31	14.5	48	1.000000504									
32	15	57	1.000000306									
33	15.5	41	1.000000186									
34	16	42	1.000000113									

	A	B	C	D	E	F	G	H	I	J	K
1	Data										
2	Time	Radiation	Theoretical Radiation								
3	0.5	1531	1513.134339		a	b	c		Sum of squares		
4	1	1321	1317.184849		1717.794	20.91056	0.281547		13864.87831		
5	1.5	1170	1146.966219								
6	2	924	999.099635								
7	2.5	885	870.6499655								
8	3	709	759.0675029								
9	3.5	706	662.1373512								
10	4	586	577.9354606								
11	4.5	512	504.7904354								
12	5	435	441.2503573								
13	5.5	387	386.0539646								
14	6	342	338.1056169								
15	6.5	310	296.4535462								
16	7	251	260.2709649								
17	7.5	223	228.8396537								
18	8	216	201.5357057								
19	8.5	194	177.8171413								
20	9	168	157.2131503								
21	9.5	140	139.3147466								



G.) And there we go, now we have our a, b and c to get a trendline and add it to the graph so there are two final steps.

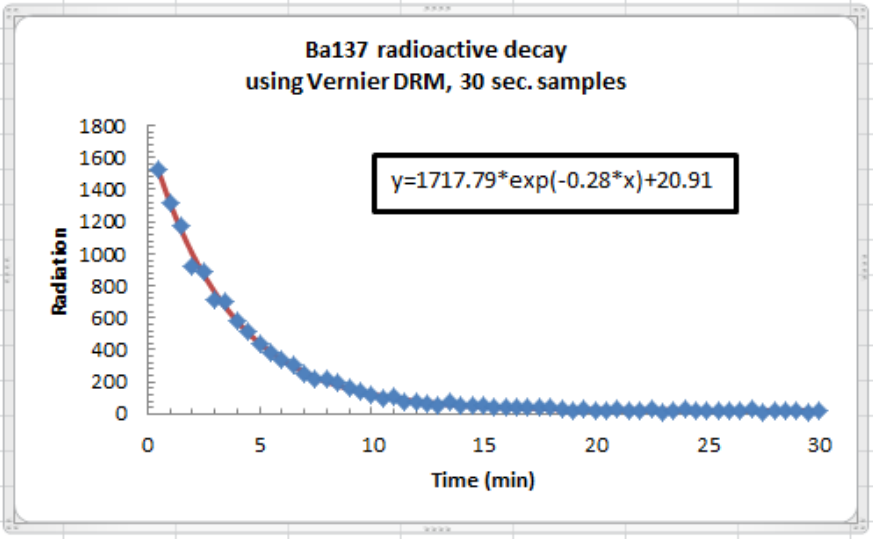
H.) First remember that the red points are THEORETICAL, we have an equation to get every single point, so this should be shown as a line, to change this right click the red dots, and go to “change series chart type” then select the smooth line in the scatter plot section, as shown here.



I.) Finally, since we have our theoretical equation lets add it to the graph using a text box, you might need to go back and look at equation (1) on the first page.

J.) Now you're finished, you should have a final graph with an equation and trendline as shown below. Congratulations you no longer need to depend on excel to find a theoretic al fit!

	A	B	C
1	Data		
2	Time	Radiation	Theoretical Radiation
3	0.5	1531	1513.134339
4	1	1321	1317.184849
5	1.5	1170	1146.966219
6	2	924	999.099635
7	2.5	885	870.6499655
8	3	709	759.0675029
9	3.5	706	662.1373512
10	4	586	577.9354606
11	4.5	512	504.7904354
12	5	435	441.2503573
13	5.5	387	386.0539646
14	6	342	338.1056169
15	6.5	310	296.4535462
16	7	251	260.2709649
17	7.5	223	228.8396537
18	8	216	201.5357057
19	8.5	194	177.8171413
20	9	168	157.2131503

a	b	c
1717.794	20.91056	0.281547

Sum of squares
13864.87831