Investigating Nuclear Stability with a Graphing Calculator

Obtain the following:: *TI-82/83 graphing calculator with ISOTOPE calculator program*

Activity One ***General Stability***

1.1 Run the program ISOTOPE and select ACTIVITY ONE to set the calculator up to begin. When the calculator screen shows "Done" continue on to 1.2 below.

1.2 Using lists L1=atomic number, L2=number of neutrons and the enclosed chart of the isotopes, plot a scatter gram (⋰) of atomic number vs. number of neutrons for the most ubundant stable isotope in the first twenty elements. Use atomic number as your manipulated variable (independent) and the cross marker (+) to mark the points.

DIRECTIONS FOR TI-82/83

[Y=] Clear all equations
Set up the [STAT] EDIT table with the following data:
L1=atomic number
L2=number of neutrons

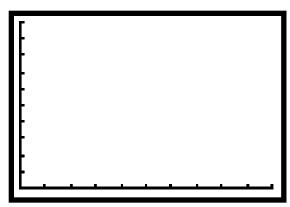
[2nd] [Y=]
Plots Off
Plot1
ON
⋰ Xlist=L1 Ylist=L2 +
[ZOOM]
ZoomStat

1.3 What does the scatter gram indicate about the relationship between the variables? *hint: Is it linear or nonlinear?*

1.4 Calculate the regression equation for the data. Enter the equation into Y1 and plot the line of "best fits". Record the regression equation and sketch the calculator screen in your lab report.

Directions for the TI-82/83

• TI-82 only
[STAT] CALC Setup 2VarStats Xlist L1 Ylist L2
• TI-82 / 83
[STAT] CALC LinReg(ax+b) ENTER ENTER
[Y=] Y1 [VARS] Statistics EQ RegEQ
[GRAPH]



Regression Equation

Y= ___________________________

1.5

a. What does this relationship indicate about stable atomic nuclei for the first 20 elements?

b. From this relationship predict the trend for the relative masses in the first twenty elements.

1.6 Using the data for the Carbon-14 isotope, enter: L3 = atomic number and L4=neutron number. Create a second scatter gram (⋰) using PLOT2 and a box marker for the data in L3 and L4. *Note: This will plot only one point for PLOT2.*

Directions for the TI-82/83

[2nd] [Y=]
Plot2
ON
⋰ Xlist=L3 Ylist=L4
[ZOOM]
ZoomStat

1.7 Update your sketch in question four to include the box point for the carbon-14 isotope.

a. What is the Carbon-14 isotope's position relative to the regression line?

b. What is "special" about atoms whose nuclear ratio lies close to that line?

c. What does this imply about Carbon-14's nuclear stability?

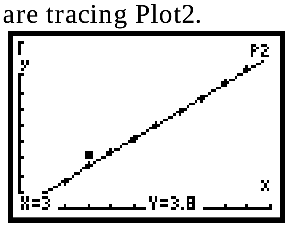
1.8 Write the formula for the daughter nuclides produced if a Carbon-14 atom were to decay and emit the following particles:

$$\frac{14}{6}C \quad \text{----->} \quad \frac{0}{-1}e \quad + \quad \textbf{?} \qquad\qquad \frac{14}{6}C \quad \text{----->} \quad \frac{4}{2}He \quad + \quad \textbf{?}$$

1.9 Using the data for the two possible daughter nuclides, enter: L3 = atomic number and L4 for neutron number (overwrite the C-14 data). Create a scatter gram using PLOT2 and a box marker for the data in L3 and L4.

1.10 By using the [TRACE] function, analyze the graph and determine whether carbon-14 undergoes alpha or beta decay. Write a chemical equation describing that decay.

[TRACE] [▲]
Until "P2" is shown in upper right corner of screen. Indicating you are tracing Plot2.



Activity Two *Stability of Heavy Elements*

2.1 Run the program ISOTOPE and select ACTIVITY TWO. This program updates the data in L1 and L2 to include the remaining stable naturally occurring isotopes (up to atomic number 92). The data is stored as L1=atomic number, L2=neutron number on your calculator.

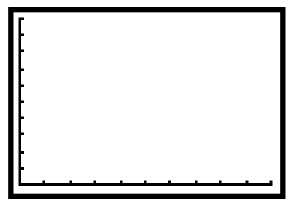
2.2 By interpreting the graph, what happens to the stability trend we established for the first twenty elements? Has it changed or stayed the same?

2.3 To find a “new” mathematical relationship for the remaining data, or the second piece of this “piece-wise” function, we need to find a regression equation. Does the data look like a line or a curve? If the trend looks to be linear, use the LinReg function. If the data looks to be a curve you must find the equation of best fits, by choosing between a log function (LnReg), an exponential function (ExpReg)and a power function (PwrReg). Use the value of the Pearson Correlation Coefficient **(r)** to judge which regression model “best fits” the new data. Remember the “best fits” model will have an **(r)** value closest to 1 or -1.

When you have determined the regression equation, store it to Y2 and graph the line of “best fits”. Record the equation and sketch the graph in your lab report.

Regression Equation

Y= __________________________



2.4

a. If we look at the proton / neutron data for the first twenty stable isotopes, what type of a mathematical function exists?

b. If we consider all of the stable naturally occurring nuclei (up to atomic number 92) what type of a function exists?

c. What does the data indicate about stable nuclei as their atomic number increases?

d. As the atomic number of an atom increases, what changes about the nucleus that would account for the difference in the mathematical stability function?

Decay Series for Uranium-238

Isotope	Half Life
Uranium-238	4x10^9 years
↓	
Thorium-234	25 days
↓	
Protactinium-234	7 hours
↓	
Uranium-234	2.7x10^5 years
↓	
Thorium-230	8x10^4 years
↓	
Radium-226	2.3x10^3 years
↓	
Radon-222	4 days
↓	
Polonium-218	3 minutes
↓	
Lead-214	27 minutes
↓	
Bismuth-214	20 minutes
↓	
Polonium-214	1.6x10^{-4} seconds
↓	
Lead-210	22 Years
↓	
Bismuth-210	5 days
↓	
Polonium-210	138 days
↓	
Lead-206	**Stable**

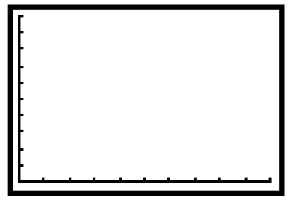
Activity Three ***Decay Series***

3.1 Run the program ISOTOPE and select ACTIVITY THREE. This program removes the data points for the stable naturally occurring isotopes but leaves the "band of stability" equation in Y1.

3.2 Some unstable nuclei cannot reach the “band of stability” by one nuclear decay. They undergo many decays in an effort to become stable. One such element is Uranium-238. Using the enclosed data series chart with L1 atomic number and L2=number of neutrons, enter the data for all of the daughter nuclides in Uranium-238’s decay series.

3.3 Set up Stat Plot 1 for a line graph ( ), with a cross marker (+), of L1,L2. Select ZOOM, ZoomStat.

Sketch the calculator screen in your lab report.

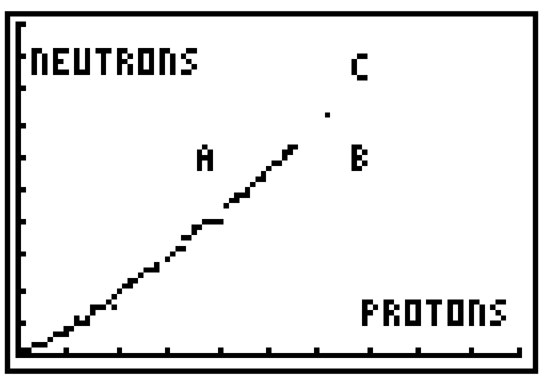


3.4 Use the TRACE function on the calculator and trace the points on the screen that represent atoms in U-238’s decay series.

3.5 Complete the following table about the types of particles emitted as the nuclides decay and move around the “band of stability”.

Movement (relative to “Band of Stability”)	*Greek symbol used for the particle released from nucleus*	*Formula for emitted particle*
left		
right		

3.6 Based upon this information we can draw some general conclusions concerning nuclei and the band of stability. Complete the chart below by identifying the types of particles emitted from nuclei in order to reach the “band of stability”. Each region, A, B and C, on the graph should require a different nuclear change in order to achieve stability.



Region	*Particle most likely emitted to achieve stability*	*Formula for particle*
A		
B		
C		

Activity Four *Nuclear Fission*

Nuclear fission is a spontaneous process whereby a large nucleus splits into two or more smaller nuclei. This process is induced by bombarding large atoms, like U-235 with neutrons, forming a highly unstable nucleus. This unstable nucleus undergoes spontaneous decay into two small daughter nuclei and emits a number of neutrons. These neutrons are moving at a very high rate of speed and can bombard other U-235 atoms and initiate other fission reactions, continuing the process by **chain reaction**. Attached is a diagram showing the neutron bombardment and subsequent nuclear chain reaction for U-235.

Nuclear fission unleashes an enormous amount of energy. The fission of 1 Kg of uranium-235 releases an amount of energy equal to the energy generated in the explosion of 20,000 tons of dynamite. If the chain reaction of uranium fission is uncontrolled, the energy release is instantaneous. This is what happens in an atomic bomb explosion. But, nuclear fission can be controlled and the energy released can be used to heat steam and produce electricity.

Like all other stars our sun runs on nuclear power. What is new is human use of nuclear energy. The nuclear energy released from only a few grams of nuclear fuel is equal to that produced by burning thousands of gallons of gasoline. In 1989 nuclear power plants generated 5% of the nation's total energy needs, and generated nearly 20% of U.S. electrical power.

Are the risks of nuclear technology worth its benefits? Some uses of nuclear technology create greater risks than others, and some offer greater benefits than others. As a voting citizen you will help influence nuclear technology's future. To better understand the risks of nuclear energy production we need a better understanding of fission. So let's go fission!!

4.1 Run the program ISOTOPE and select ACTIVITY FOUR. This program removes the data points for the stable naturally occurring isotopes but leaves the "band of stability" equation in Y1.

4.2 Using the enclosed fission chart with L1=atomic number and L2=number of neutrons, enter the data for all of the daughter nuclides shown.

4.3 Set up Stat Plot 1 for a scatter gram (⋰), with a box marker, of L1,L2. Select [ZOOM], ZoomStat.

4.4 Sketch the plot into your lab notebook. Explain what the plot tells you and why you think this pattern occurs.

4.5 Make a hypothesis concerning the stability of the fission daughter nuclides.

4.6 If these daughter products are radioactive, what type of decay will they undergo to become stable? (Which zone are they in?)

4.7 Update lists L1 and L2 to include the data for the U-236 parent isotope. Set up Stat Plot 1 for a scatter gram (⋰), with a box marker, of L1,L2. Select [ZOOM], ZoomStat.

4.8 Is there a mathematical relationship here for the points plotted? Figure the line of regression for the data in L1, L2. Sketch the graph and record the regression equation.

4.9 What is the significance of the slope of this line? What does it mean about the stability of the parent-daughter products of nuclear fission?

The daughter nuclides are physiologically important to humans because they can accumulate in the body. The following table illustrates areas of accumulation and stability for some of the fission daughters:

Isotope	**Area of Accumulation**	**Half-Life**
Strontium-90	Bones	27.7 yr.
Krypton-92	Lungs	1.4 yr.
Cesium-144	Muscles	1-2 min.
Xenon-144	Lungs	50 min.

Let's look further at one of the fission products, Kr-92. We established above that Kr-92 is unstable and will decay via beta decay. But will Kr-92 become stable with one decay, or will it decay by a series?

4.10 If each decay from Kr-92 requires the conversion of a neutron to a proton, determine the nuclear composition of the first three daughter products.

4.11 Using the data from 4.10 above, construct a mathematical equation describing the relationship of number of neutrons in each daughter's nucleus versus the number of protons. Make the equation of the form Y=AX+B.

4.12 What is the "atomic significance" of your coefficients for A and B in the equation you have created in 4.11?

4.13 Enter the equation from 4.11 into Y3 and plot the function with respect to the stability function.

4.14 Using the intersect feature of the calculator, calculate the point of intersection of the Kr-92 decay function with the stability function. This point represents the nuclear composition for the theoretical terminal nuclide in Kr-92's decay series.

Directions for the TI-82/83

[Y=]
Y3=
[GRAPH]
[2nd] [TRACE] intersect
Use the arrow keys to choose the Kr-92 decay line as your 1st. curve. Choose the "band of stability" as your 2nd. curve. Position the cursor close to the intersection to Guess.

4.15 What is the formula (element and mass) for the stable element from Kr-92's beta decay chain? Write a decay series showing all of the daughter nuclides as Kr-92 decays to a stabile isotope? Is this trend similar for all of the fission daughters? Explain.

4.16 What conclusions can you draw about spent fuel radioactive waste from fission reactions?

By federal law, reactor waste must be stored on site of production, usually in nuclear waste storage tanks. Final disposal of radioactive waste is the responsibility of the U.S. government and we currently do not have any permanent disposal sites.

Consider yourself a policy maker in a community split between proponents for using nuclear energy and those against. Many feel that nuclear waste generated from fission reactions represents "Pandora's Box".

- What do they mean by this statement?
- Do you have enough data to draw a firm conclusion with regards to spent fuel?
- What additional data do you need?
- Where would you go and whom would you talk to for more information?