**7.1 Investigating half-life Name \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**

**Introduction**

The probability of a radioactive isotope decaying during the half life is 50-50. Since the probability of getting a ‘head’ when flipping a coin is also 50-50, repeated coin tosses can be used to simulate decaying atoms. Probability theory shows that the greater the number of coin tosses, the closer the accumulated results will be to the 50-50 split. The calculator program “Prob Sim” (Probability Simulation) will be used to increase the total number of coin tosses. You will use the Calculator Simulated Data instead of accumulated class data.

**Part 1: Half-Lives and Pennies**

1. Place 100 pennies in a shirt box. Turn all the pennies to heads.
2. Close the box gently shake it for several seconds in all directions to randomize the heads or tails.
3. Open the box and remove any penny that is head down (tails up) Count the remaining pennies, and record this number.
4. Repeat steps 2 and 3 until you have no pennies to place in your cup.
5. Calculate the theoretical value for the number of pennies that would be left if exactly half of them ‘decayed’ during each toss. (Do NOT round off your answers even though it is not possible to have a fractional # of pennies left.)

**Part 2: Calculator Pennies**

Note – in the directions below, words in all UPPER CASE are keys to push on the calculator. When using the program, you will notice that options often appear across the bottom of the calculator screen. When you push the calculator key below these options you are actually performing that operation. In the directions below, the calculator key you are to press will be given in UPPER CASE – the program option you are doing will be given in a parentheses immediately after the key label.

1. Turn on your calculator.
2. Push APPS.
3. Push the down arrow until the program ‘Prob Sim’ is highlighted. Push ENTER.
4. The opening screen for the program appears. Push ENTER again.
5. The option ‘Toss Coin’ is highlighted. Push ENTER again.
6. Push WINDOW (Toss). The calculator will flip one coin.
7. Push GRAPH (Clear). The calculator erases the data from this toss.
8. Push Y = (Yes).
9. Push TRACE (+50). The calculator rapidly tosses the coin 50 times. Repeat this step until you have tossed 1000 coins.
10. Push Y = (Esc)
11. Push GRAPH (Tabl). The calculator displays a table with the total number tosses in the first column, the results of each toss in the middle column and the cumulated # of Heads in the right column. Enter the total number of heads after 1000 tosses in the data table. You now need to re-toss this number of coins (as you did with the pennies). Use the appropriate combinations of 50, 10 and single coin tosses to reach this total. When you do single tosses you will need to count them yourself as the accumulated number does not show on the calculator screen. To begin again proceed as follows:
12. Push Y = (Esc). This will allow you to leave this set of data.
13. Push Y = (Yes). This will clear the data.
14. Push ENTER. You are now back at step 5. Repeat steps 5 – 11 as needed to get to the desired # of tosses. Record the # of heads for 2 half lives. Repeat until you have no heads.
15. You have now completed this simulation. Push the following keys to leave the program: Y = (Esc). Y = (Yes). GRAPH (Quit) Y = (Yes).
16. Calculate the theoretical value for the number of heads that would be left if exactly half of them ‘decayed’ during each cycle. (Do NOT round off your answers even though it is not possible to have a fractional # of pennies left.)

**Data DATA for Part 1 DATA for Graph 2**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **# of ½**  **Lives** | **# of Heads Remaining**  **Penny Toss Data** | **Theoretical**  **Value** |  | **# of Heads Remaining**  **Simulated Calculator Data** | **Theoretical**  **Value** |
| **0** | **100** | **100** |  | **1000** | **1000** |
| **1** |  |  |  |  |  |
| **2** |  |  |  |  |  |
| **3** |  |  |  |  |  |
| **4** |  |  |  |  |  |
| **5** |  |  |  |  |  |
| **6** |  |  |  |  |  |
| **7** |  |  |  |  |  |
| **8** |  |  |  |  |  |
| **9** |  |  |  |  |  |
| **10** |  |  |  |  |  |

**Part 1 and Part 2 Analysis –**

1. Prepare the attached graphs for your Part 1 and Part 2 data by selecting appropriate scales. Label the *x*-axis “# of half-lifes,” and label the *y*-axis “Number of pennies.” Be sure to label both sets of axes and Title each graph. (Something more than Part 1 or Part 2)
2. Graph the theoretical values for Part one on the Part 1 graph and Part 2 on the Part 2 graph. Draw a smooth curve through these points.
3. Graph your results for 100 pennies (manually tossed) and your results for 1000 pennies (calculator simulation). Do not connect these points. The curve from the theoretical values should look like a best fit line.

**Answer the following questions**

1. Compare between your penny data and the simulated calculator data:

a) Which of your two graphs gives the smoother theoretical curve?\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

b) Which of your experimental data sets gives values closer to the theoretical curve? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

c) Which set of data, manually tossing 100 pennies or the calculator simulation of 1000 tosses, would you have expected to be closer to the theoretical value? \_\_\_\_\_\_\_\_\_\_\_\_\_\_ Why? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

2. Out of a set of 500 pennies, how many would you expect to be left over after 3 half-lives? \_\_\_\_\_

3. How many half-lives on the calculator would it take for 10,000 pennies to be eliminated? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

4. If you start with 1 mole (6.02 x 1023 atoms), how many half-lives does it take to get down to one atom? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_





**Part 3: Alpha Decay PhET Simulation**

Open https://phet.colorado.edu/en/simulation/alpha-decay

1. Investigating “Alpha Decay”
   1. Start on the **Single Atom** tab - observe the decay of Polonium -211. Use **Reset Nucleus** to watch the process repeatedly. Write a description of what happens in the alpha decay of an atom.
   2. Check your ideas with the “Custom” atom and reflect on your ideas.

New ideas here:

* 1. Did you find the graph helpful or not? Explain
  2. Verify your ideas by using the periodic table or other resources to determine what the differences are between Polonium with a mass number of 211 and Lead with a mass number of 207. Also, use other resources to see what “Alpha Decay” means and cite at least one valid source.

Cites here:

* 1. Practice using your ideas by predicting what would happen if the following undergo alpha decay:
     1. Radium-226 \_\_\_\_\_\_\_\_\_\_**+** \_\_\_\_\_
     2. Plutonuim-240 \_\_\_\_\_\_\_\_\_\_**+** \_\_\_\_\_
     3. Uranium-238 \_\_\_\_\_\_\_\_\_\_**+** \_\_\_\_\_

1. Investigating “Half-life” - The **Multiple Atoms** tab may be helpful
   1. Use the Charts at the top of the sim to test ideas you might have about half-life. Make sure to use multiple samples and substances with a variety of half-lives. Make a data table that shows your tests.

Data Table here:

* 1. In your own words, describe what “half-life” means.
  2. Check your ideas by drawing predictions **without** using the sim for the following scenario:

If you have a *substance* that has a half- life of 1.5 seconds make predictions of what will happen by sketching the pie graphs indicating the number of the *substance* and it’s *decayed atoms*for a reaction starting with 40 total atoms.

t= 0.5s t=1.0s t=1.5s t=2s

1. Use the sim to test the scenario. Copy the graphs. ( **Pause**  and **Step ** may help)

t= 0.5s t=1.0s t=1.5s t=2s

t=2s

1. How do your predictions compare to the results shown in the sim?
2. Run the scenario repeatedly and compare the results of multiple trials. Use the Data table to show your results:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Time(s) | Trial 2 | Trial 3 | Trial 4 | Trial 5 |
| 0 |  |  |  |  |
| 0.5 |  |  |  |  |
| 1.0 |  |  |  |  |
| 1.5 |  |  |  |  |
| 2.0 |  |  |  |  |

1. What ideas do you have to explain the similarities and differences in the data and also your predictions?
2. Try another substance with a different half-life to see if your conclusions make sense. Describe your test, results, and conclusions.
3. Practice using your ideas: Is it reasonable to assume that if you start with 10 atoms of Polonium, that 0.5s later only 5 will remain? What if you start with 500 atoms? Explain.

**Part 4: Real Nuclide Database** http://atom.kaeri.re.kr/nuchart/

(adapted from http://www.pstcc.edu/nbs/WebPhysics/Expm%2010.htm)

**Types of Radiation:**

Three important types of radiation are ***alpha particles***,***beta particles***,and***gamma rays*.**

***α-particles*** are ***helium nuclei*** that eject from some radioactive isotopes that undergo spontaneous decay or through fission**.**  Therefore an ***α-particle*** is made of ***2 protons and 2 neutrons*.**

|  |  |
| --- | --- |
| When a nucleus undergoes an  ***α***-decay, the daughter element has 2 fewer protons, and therefore it moves 2 elements lower in the periodic chart**.** | http://www.pstcc.edu/nbs/WebPhysics/E2120D1005.gif |

***β-particles*** are ***fast moving electrons*** or ***fast moving positrons*.**  A negatively charged beta particle ***β -*** is ***an electron***, and a positively charged beta particle ***β+*** is ***a positron.***

|  |  |
| --- | --- |
| For an electron to come out of a nucleus, ***a neutron turns into a proton, an electron, and an anti-neutrino,*** as shown on the right**.**  The resulting element gains an extra proton while losing a neutron**.** | http://www.pstcc.edu/nbs/WebPhysics/E2120D1006.gif |
| An example is shown on the right**.**  ***This means that the number of  protons increases by 1, and the daughter element becomes one element higher in the periodic table.*** | http://www.pstcc.edu/nbs/WebPhysics/E2120D1007.gif  Nitrogen, the daughter, is a higher element than carbon in the periodic table**.** |

***γ-rays*** are highly energetic electromagnetic radiation**.**  ***Gamma rays*** are very penetrative and therefore dangerous due to their extremely small wavelengths**.**  Alpha rays can be stopped by putting suitable clothing on and even by human skin if they are not very energetic**.**  ***Beta rays*** can be stopped by a few millimeters of aluminum**.**  The radiation concerns of nuclear reactors are mainly for gamma ray radiation**.**

|  |  |
| --- | --- |
| When a nucleus is in an excited state, it sometimes emits high energy electromagnetic radiation (a γ- ray) to get out of that state**.**  The excited state is usually shown by a star**.**  An example is shown on the right**.** | http://www.pstcc.edu/nbs/WebPhysics/E2120D1008.gif |

**Information Given in the Squares of the Chart of Nuclides:**

Guidelines for understanding the nuclides in the chart are given below**:**

**I. Gray shaded square: (*Stable Nuclide*) Elemental percent abundance 🡪 molar mass**

|  |  |
| --- | --- |
| ***Isotopes that occur in nature and are classified as stable*** | http://www.pstcc.edu/nbs/WebPhysics/E2120D1009.gif |

**II. White or "color" square: (*Artificially Produced Radioactive Nuclide*)**

|  |  |
| --- | --- |
| ***Artificially produced radioactive isotopes.***    Some charts have color coding for the range of half-lives and neutron absorption properties**.** | http://www.pstcc.edu/nbs/WebPhysics/E2120D1010.gif |

**III. Black rectangles across the top of square:**

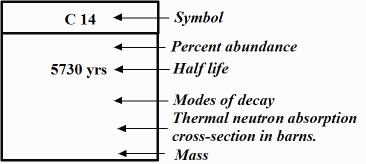
**a. On gray-shaded square:**

***Radioactive nuclide with long half life (Considered Stable)***

|  |  |
| --- | --- |
| Radioactive nuclide found in nature with ***very long half-life*.**  An example  is**:**  **Ce -142**  ***T*1/2= 5x1015 years.**   ***Such long half-life is considered to be stable.*** | http://www.pstcc.edu/nbs/WebPhysics/E2120D1011.gif |

**b. On white square:**

***Radioactive nuclide found in nature with relatively short half life***



**VI. Smaller black rectangle near top of square:**

**Nuclide is a member of a natural radioactive decay chain.**

|  |  |
| --- | --- |
| Nuclide is a member of a natural radioactive decay chain**.** The  historic symbol is inserted in the black area**.**  Example**:** **Ra A** for ***Po-218***, and ***UX1*** for ***Th-234*.** | http://www.pstcc.edu/nbs/WebPhysics/E2120D1013.gif |

**V. Black triangle at bottom corner of square: Refer to item 1 above.**

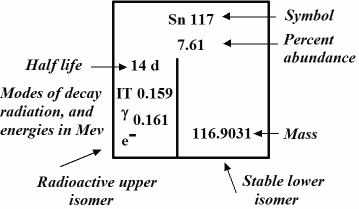
**This indicates nuclide is formed by fission of U-235 or Pu-239.**

|  |  |
| --- | --- |
| Example**:** ***Xe-140*** and ***Sr-94*** in the induced fission reaction of ***U-235*** | http://www.pstcc.edu/nbs/WebPhysics/E2120D1014.gif |

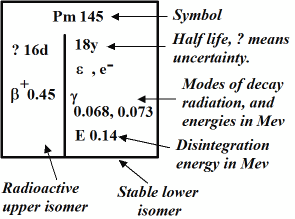
**VI. Vertically divided square:**

This is indicative of a nuclide with isomeric or metastable states**.**  The nuclide possesses different states with different radioactive properties**.**  The nuclei of the different states of a particular nuclide are called "***nuclear isomers***" (same ***Z and N numbers***, but different radioactive properties)**.**  If two isomers exist, the higher energy state is shown on the left**.**  If three isomers exist, the higher energy state is shown on the left with the lower energy state below it or to the right of it, and the ground state (the lowest energy level) to the right of both or below them**.**

**Two isomeric states, one stable:**



**Two isomeric states, both radioactive:**



The arrangement of nuclides in the chart is such that the nuclear processes can be understood by examining the chart carefully**.**  Following is the explanation of two such processes**:**

1**.** **Induced Reactions**

An induced reaction is done by bombarding a target nucleus by a particle, a neutron, a proton, or an alpha particle, for example**.**  There is an "***in***" particle colliding with the target nucleus, and an "***out***" particle that could result in addition to the altered target nucleus**.**

When ***(9, 4)Be*** is bombarded by an alpha particle ***(4, 2)He***, the compound nucleus ***(13, 6)C\**** is located two squares diagonally upward to the right on the chart of nuclides**.**  This excited nucleus then releases a neutron, and the product nucleus ***(12, 6)C*** is located one square to the left of the excited nucleus ***(13, 6)C\**.**

http://www.pstcc.edu/nbs/WebPhysics/E2120D1017.gif

The following two diagrams are useful for determining the ***relative chart locations of the products of various nuclear processes.***

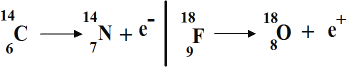
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| |  |  | | --- | --- | | n | *neutron* | | p | *proton* | | d | *deuteron* | | t | *triton (3H )* | | **α** | ***alpha particle*** | | **β** | ***negative electron*** | | **β** | ***positron*** | | **ε** | ***electron capture*** |   The last four transformations are the most common | http://www.pstcc.edu/nbs/WebPhysics/E2120D1018.gif |

**Displacements caused by nuclear bombardment reactions:**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| http://www.pstcc.edu/nbs/WebPhysics/E2120D1019.gif | |  |  | | --- | --- | | n | *neutron* | | p | *proton* | | d | *deuteron* | | t | *triton (3H )* | | α | *alpha particle* | | β | *negative electron* | | β | *positron* | | ε | *electron capture* | |

**Radioactive Decay:**

In this case, there is no bombardment of a target nucleus**.**  A radioactive nuclide spontaneously emits radiation and normally moves toward becoming more stable**.**  The daughter nucleus may be obtained from the diagram that contains the "***in***" and "***out***" particles**.**  Two spontaneous decays are shown below that follow the rules in the diagram that has "***in***" and "***out***" particles in it**.**



Most nuclear reactions are studied by inducing a collision between two nuclei where one of the reacting nuclei is at rest (the *target* nucleus) while the other nucleus (the *projectile* nucleus) is in motion.

(Exceptions to this occur both in nature and in the laboratory in studies where both the colliding nuclei are in motion relative to one another). But let us stick to the scenario of a moving projectile and a stationary target nucleus. Such nuclear reactions can be described generically as

projectile P + target T 🡪 emitted particle X + residual nucleus R

For example, a reaction might occur by bombarding 14N with alpha particles to generate an emitted particle, the proton and a residual nucleus, 17O. A shorthand way to denote such reactions is, for the general case, T (P,x) R or for the example above 14N (,p) 17O. In a nuclear reaction there is conservation of the number of protons and neutrons (and thus the number of nucleons). Thus the total number of neutrons (protons) on the left and right sides of the equations must be equal.

Use the information and guidelines you learned under "Theory" to answer the following questions**:**

1. How are the ***isotopes*** of an element arranged in the chart**?**

1. How are the***isotones***arranged in the chart? ***Isotones*** are nuclides with the same number of neutrons**.**

1. Is the phrase "isotones of an element" correct**?**

1. Nuclides with the same mass number are called ***isobars*.** What would be the orientation of a line that connects an***isobaric*** series?

1. List the percent abundances of the naturally occurring nuclides of (a) oxygen and (b) uranium**.**  Do they add up to 100 percent?  If not, explain**.**

1. List the elements that have only one stable isotope**.**

1. List two elements that have at least 8 stable isotopes**.**  Give the number of isotopes of each**.**

1. List the element that has the greatest number of radioactive isotopes**.**  Give the number of isotopes**.**

1. For each of the following half-life ranges, list a radioactive nuclide and its half life**:**

                  Seconds       Days

                  Minutes            Years

                  Hours

1. List 3 nuclides with a half-life of less than 1 second, and 3 with a half-life of more than 106 years**.**

1. Beginning with the following radioactive parent nuclei, trace the decay processes and describe the mode and direction of each decay process on the chart**.**  List each of the nuclides in the decay chain until you land on a stable nuclide.

a) Oxygen 20 (O-20)

b) Fe-52

c) Po-197

d) Ho-162

1. Using the chart of nuclides, write each of the following reactions**.**   Provide the product nucleus of each reaction**.**

            (a)  10B (n, α)

            (b)  16O (n, p)

            (c)   7Li (p, γ)

            (d)  17O (γ, n)

            (e)  32S (n, p)

            (f)  3H (d, n)

            (g)  2H (t, n)