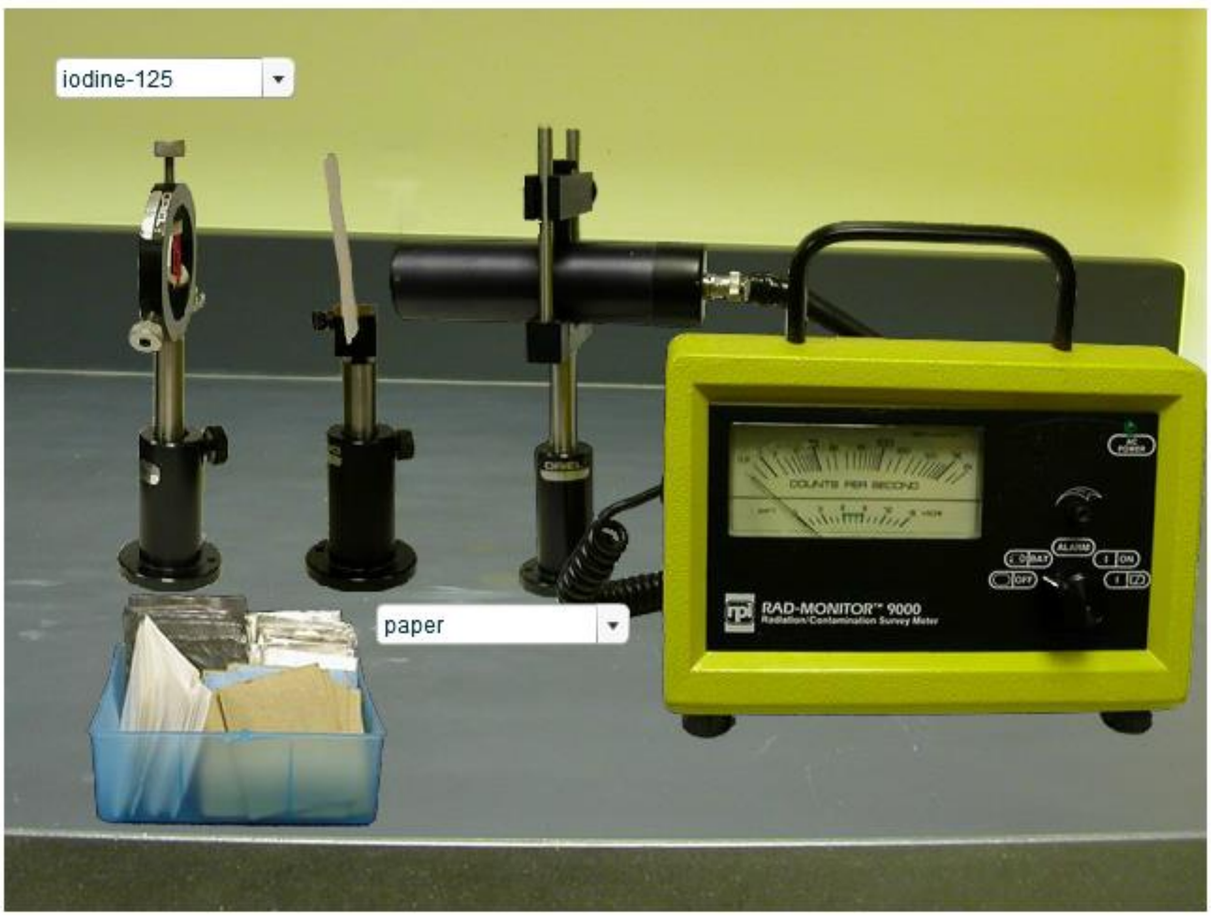
Virtual Nuclear Chemistry Laboratory

Note: data for this experiment can be generated using the excellent Nuclear Chemistry module at Virtual General Chemistry Laboratories at the University of Colorado at Colorado Springs (https://www.uccs.edu/vgcl/)

Part A – Types of Radiation

The radiation produced by radio nuclides can be categorized into α-, β-, and γ-radiation, based on how far it can penetrate into a barrier. a-radiation is the least penetrating (most easily stopped), and γ-radiation is the most penetrating (hardest to block.) Based on the following data, indicate how each nuclide decays, by α-, β-, of γ-particle emission. A picture of the experimental apparatus is shown below:



The gauge indicated radiation levels in “Counts per second”. The nuclides used in this section are:

Nuclide	Shield	Run A	Run B	Run C	Average	Type of radiation
^{59}Fe	none					
	Paper					
	1 mm cardboard					
	1 mm Al					
	1 mm Pb					
^{67}Ga	none					
	Paper					
	1 mm cardboard					
	1 mm Al					
	1 mm Pb					
^{125}I	none					
	Paper					
	1 mm cardboard					
	1 mm Al					
	1 mm Pb					
^{32}P	none					
	Paper					
	1 mm cardboard					
	1 mm Al					
	1 mm Pb					
^{222}Rn	none					
	Paper					
	1 mm cardboard					
	1 mm Al					
	1 mm Pb					
^{85}Sr	none					
	Paper					
	1 mm cardboard					
	1 mm Al					
	1 mm Pb					

Iron-59: Iron-59 is used in blood tests to determine the level of iron in the blood and bone marrow function.
Gallium-67: Gallium-67 is used in abdominal imaging, tumor detection, and in the treatment of lymphomas.
Iodine-125: Iodine-125 is used in the treatment of brain cancer and in the detection of osteoporosis.
Phosphorus-32: Phosphorus-32 is used in the treatment leukemia and pancreatic cancer.
Radon-222: Formed by the decay of radium-226 and uranium-238 present in soils, radon-222 gas can collect in buildings, posing a threat of lung cancer.
Strontium-85: Strontium-85 is used in brain scans and for the detection of bone lesions

Based on your observations, classify each nuclide as an α-, β-, or γ-emitter.

Based on your findings, write a nuclear reaction for the decay observed for each of the nuclides used in these measurements. Make sure your nuclear charges balance, as well as your mass numbers.

$^{59}Fe \rightarrow$ _______ + _______

$^{67}Ga \rightarrow$ _______ + _______

$^{125}I \rightarrow$ _______ + _______

$^{32}P \rightarrow$ _______ + _______

$^{222}Rn \rightarrow$ _______ + _______

$^{85}Sr \rightarrow$ _______ + _______

Part B – How does distance matter?

For this part, a Gallium-67 source is used without a barrier between it at the detector. The following activities are measured when the source is the indicated distance from the detector (shown in the table to the right.)

Which functional form best fits the data?

1. $y = Ax^{-b}$
2. $y = Ae^{-bx}$

3. $y = \frac{A}{x}$

Distance (cm)	Counts Run 1	Run 2	Run 3	Average
1.0				
2.0				
3.0				
4.0				
5.0				
6.0				
7.0				
8.0				
9.0				
10.0				

Try these models and decide on the best fit. Indicate your justification in the space below.

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Part C – Carbon-14 Radio Dating

Carbon-14 decays by β-particle emission:

$$^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}\beta$$

The decay process follows 1st order kinetics, with a half-life of 5730 years. This can be used to determine the length of time since a living thing stopped ingesting carbon-14 based on the fraction of carbon-24 activity exhibited relative to a current sample that is similar.

Example: A sample of wood from a recently felled tree emits β-particles due to the decay of carbon-14 at a detection rate of 94 counts per second. By comparison, a sample of wood taken from the Bristlecone Pine Forest in the White mountains of California emits at a detection rate of 25.2 counts per second. How old is the sample of wood from the Bristlecone Pine Forest?

Solution: The decay of carbon-14 follows first-order kinetics. As such

$$[A] = [A]_0 e^{-kt}$$

where the concentration of ^{14}C is proportional to the number of counts per second detected for a sample. So, the age (t) can be found from

$$25.2\ s^{-1} = (94\ s^{-1})e^{-kt}$$

But what is *k*? This can be found from the half-life.

$$k = \frac{\ln(2)}{t_{\frac{1}{2}}} = \frac{\ln(2)}{5730\ yr} = 1.21 \cdot 10^{-4} yr^{-1}$$

So

$$25.2\ s^{-1} = (94\ s^{-1})e^{-1.21 \cdot 10^{-4} yr^{-1}(t)}$$

Or

$$t = 10\underline{8}83.6\ yr$$

The following data are collected for various organic samples. Based on the fraction of activity recorded for present-day samples, estimate the age of each sample in years. The half-life of carbon-14 is 5730 yr.

Experiment 5 - Radiocarbon Dating

Sample		Activity (counts/sec)	Age (yr)
Present-day materials			
	wood	92	0
	paper	75	0
	bone	27	0
Archaeological objects			
	bone, Bering land bridge	9	
	wood, tomb of pharoah Zoser	54	
	bone, La Brea tar pits	7.4	
	paper, Dead Sea scrolls	59	
	skull, Laguna Beach, CA	3.9	
	wooden timber, Stonehenge	52	
	bone, Pedra Furada, Brazil	0.6	
	wooden beam, India	47	

Based on these data, calculate the age of each archaeological sample.

The oldest sample in the data set is ________________________________.

